CALCIUM CARBONATE APPLICATION AT PUSLINCH LAKE (CAMBRIDGE, ONTARIO) FOR PHOSPHORUS CONTROL: THEORY VERSUS PRACTICE

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CALCIUM CARBONATE APPLICATION AT PUSLINCH LAKE (CAMBRIDGE, ONTARIO) FOR PHOSPHORUS CONTROL: THEORY VERSUS PRACTICE

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ABSTRACT

A summary and history of data collected at Puslinch Lake (near Cambridge, Ontario) are provided. Information pertaining to bacterial densities, phosphorus loading, hydrology, sediment chemistry, macrophytes, fish, plankton and water chemistry are summarized. The lake is a shallow, wind mixed, eutrophic, hardwater system suffering from excessive phytoplankton blooms (over 70 μg/L chlorophyll a) with Cyanophycean genera (Aphanothece, Chroococcus, Lyngbya and Oscillatoria) dominating in summer and fall. Zooplankton densities are relatively low with cyclopoid copepods and non-daphnid cladocerans predominating. Fish populations are poorly developed. Macrophytes can cover extensive portions of the lake with Potamogeton crispus dominating in the spring and Chara dominating during the remainder of the season. Beach closures due to high bacterial counts are common.

Residents were surveyed regarding their opinions on lake water quality, recreational opportunities and lake rehabilitation. In September, 1988, 76.4 tonnes of calcium carbonate powder were applied in water slurry form over the surface of the lake in an attempt to precipitate phosphorus and improve water quality. The experiment was unsuccessful in improving water quality.

Future rehabilitation of Puslinch Lake should include a program of phosphorus loading controls and partial or complete removal of flocculent, nutrient rich surficial sediments.

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INTRODUCTION

1. General

Puslinch Lake (43°25′ 80°16′) is a natural hardwater lake located in Wellington County just northeast of the city of Cambridge, Ontario. The lake basin is composed of a series of sandy and stony glacial till deposits (Dryden and Smith and Kilborn Engineering 1966, M.N.R. and M.T.C. 1977). The lake has a surface area of 163 ha, a volume of 2.27 X 10^6 m^3, a maximum depth of 6 m and a mean depth of 1.4 m (Fig. 1). Much of the bottom is covered in approximately 1 to 2 meters (or more) of organic mud which overlies a layer of coarse sand. Puslinch Lake has no defined inflow stream and presumably is filled with water by a combination of local surface run off and ground water springs under the lake surface (Dryden and Smith and Kilborn Engineering 1966). The lake outflow is a swampy area on the north shore which is drained by two culverts under Townline Road that connect to a creek that flows into the Speed River.

The north shore has a beach, trailer park, marina and cottages. Many of the cottages are year round residences (Whitehead 1980). McCormick's Point on the south shore also has a well established cottager population. Much of the western lake shore is owned by the Grand River Conservation Authority (GRCA; Hans et al. 1981). The eastern lake shore tends to be swampy and muddy with little development.

2. Nearshore Bacterial Data

The city of Guelph Health Unit has been collecting beach water samples at Puslinch Lake for bacterial testing for decades. High coliform counts leading to beach and well closures have been on record since the 1960's. The north shore experienced perennial problems with contaminated shallow wells caused by a high water table and inadequately sized tile beds (small lots) which rendered septic systems nearly inoperable. Year round use of what were basically seasonal septic facilities exacerbated the situation (Marilyn Lee, Ryerson Polytechnical Institute, pers. comm.).

Sampling by Whitehead (1980) indicated that many sites around the lake had high levels of faecal coliform bacteria. He considered this to indicate sewage contamination and suggested that septic system inspections were in order. In July and August 1982, 136 homes around the lake were inspected by the Guelph Health Unit. Only a couple of septic systems were found to be faulty and 12 homes had unacceptable drinking water quality. Yet, throughout the 1983 to 1990 period beach closures and poor water quality plagued the area. A small scale sanitary survey conducted by the Guelph Health Unit in the summer of 1990 uncovered only one malfunctioning septic system (Allan Haley, Wellington-Dufferin-Guelph Health Unit, pers. comm.).

The sources of bacterial contamination at Puslinch Lake are ill defined at present. Septic systems remain suspect but evidence is lacking. A potentially important source of

bacteria could be aquatic birds (see below). There is a controversial literature surrounding aquatic birds and bacterial contamination of surface waters (Fennell et al. 1974, Brierley et al. 1975, Benton et al. 1983). A comprehensive survey of nearshore and open water sites for a spectrum of bacterial forms (total coliform, faecal coliform, faecal streptococci, Pseudomonas aeruginosa, Staphylococcus aureus, etc.) should be performed in late summer to determine if the source is predominantly human or animal. Some of the bacteria may be proliferating in the warm, nutrient rich nearshore waters of the lake rather than simply being imported from some external source.

3. Phosphorus Loads

Whitehead (1980) noted an increase in year round usage of cottages over time at Puslinch Lake along with increased grey-water production from washing machines, dishwashers, etc. A disturbing number of homes may still not have proper grey water disposal methods into septic tile fields (Marilyn Lee, Ryerson Polytechnical Institute, pers. comm.). Anthropogenic phosphorus loading to the lake has very likely been increasing over time.

It is possible to estimate the extent of phosphorus loading to Puslinch Lake from septic sources. It is reasonable to assume that all of the anthropogenic phosphorus produced by tile beds within 300 m of the lake shore will eventually enter the waters of Puslinch Lake. Septic tank / tile field systems are designed for bacterial containment, not

phosphorus containment. A good discussion on septic system phosphorus loadings can be found in Dillon et al. (1986). Their formula for the calculation is:

$$J_A = 0.8 \times 10^6 \text{ mg P} \cdot \text{usage} \cdot (1 - R_s)$$

where J_A = anthropogenic TP input

usage = capita years per year

R_s = retention capacity of sewage system

For Puslinch Lake, usage = 1 per person if a year round dwelling and 0.17 if seasonal (two months per year usage). R_s was conservatively estimated at 0. Utilizing data on near shore septic tank systems from the 1982 sanitary survey mentioned above, 28 homes were seasonal dwellings with a total of 64 inhabitants (9 kg P per year loading) and 58 homes were permanent dwellings with a total of 151 inhabitants (121 kg P per year loading). The maximum total phosphorus loading estimate to Puslinch Lake from septic tile beds is therefore 130 kg P per year. Although this value assumes no long term retention of phosphorus by tile beds, it is a reasonable estimate as the septic systems are old and the tile fields are likely phosphorus saturated (Archie McLarty, MOE Hamilton, pers. comm.). Also, quite a few waterfront homes were not included in the 1982 survey and there are presently more seasonal and permanent cottagers than in 1982. Seasonal usage value estimates can be higher than 0.17 as well (Neil Hutchinson, MOE Dorset, pers. comm.).

Another potential source of phosphorus to Puslinch Lake are thousands of ring bill gulls (Laurus delawarensis) which feed at land sites during the day and come to the

lake in the afternoon to roost. The phenomenon occurs from mid summer (July or August) to freeze-up in fall (November or December). Approximately 10 to 11 X 10^3 gulls roost on the lake each evening during that season (Bruce Buckland, MNR Cambridge, pers. comm.). A rough estimate of the phosphorus loading that these birds created can be made using the data from Bedard et al. (1980). They found that a well fed ring bill gull of 0.52 kg mean weight produced 10 g (dry weight) of excrement per day. Each bird produced approximately 170 mg of phosphorus per day. If a 120 day season (August through October) of gull roosting on Puslinch Lake is assumed along with 11 X 10^3 birds per day, the result is 1.32 X 10^6 bird-days per year. The phosphorus load is then 224 kg P per year. The calculation is a worst case scenario as the birds do not stay at the lake all day long.

Canada geese (Branta canadensis interior) populations are also significant and added to the bird based phosphorus load. The number of geese residing at Puslinch Lake varied greatly over time, but a fair estimate would be approximately 200 geese per day during the full ice free season (Bruce Buckland, MNR Cambridge, pers. comm.). Manny et al. (1975) monitored droppings from a flock of Canada geese at a frozen lake which were feeding on local forage (i.e. the birds were not given extra food). The birds were 2.56 kg average weight and defecated approximately 28 times per day. An average dropping was 1.17 g dry weight and contained 1.34% phosphorus. The average goose in that flock therefore produced 0.439 g of phosphorus per day. If one assumes that in the Puslinch Lake case there were 200 geese per day and a 270 day ice free season (March 1

to November 30), this leads to 5.4 X 10^4 bird-days per year. The phosphorus load is then 24 kg P per year. This value could be lower because goose droppings can contain less than 1.34% phosphorus (Rob Harvey, PLPOA, pers. comm.).

Adding gull and geese loadings together gives a value of 248 kg P per year. This value is very approximate but does serve to indicate that birds were an important source of phosphorus to the lake, probably as important as septic tile beds.

The sum of septic and bird loadings (378 kg P per year) does not provide an estimate of the sum of all phosphorus loading to the lake. Other potential sources include surface run off (fertilizers, soil release of phosphorus), direct rainfall, ground water and internal phosphorus loading. Given the volume of Puslinch Lake (2.27 X 10^6 m^3), the incomplete and very rough value of 378 kg P per year leads to an average lake total phosphorus concentration of about 0.17 mg/L as P. This value falls at the high end of concentrations normally observed in the lake and suggests that a significant proportion of the phosphorus entering Puslinch Lake becomes tied up in the sediments.

4. Sediment

The organic mud overlying the sandy, granular bottom of the lake is very

flocculant. Most of Puslinch Lake is less than 2 m deep and anecdotal observations at the site indicate that the summertime activity of powerful motorboats resuspends the mud and may add to the lakes turbidity (Archie McLarty, MOE Hamilton, pers. comm.).

On December 10, 1987 surficial sediment samples (cores up to 60 cm deep) were taken in triplicate from four sites on the lake, off McClintock's Marina (site A), the east shore (site B), the deepest part of the lake (site C) and the west side (site D). All samples were highly organic with most particles falling in a size range smaller than 45 μm (many particles were "fine silt"). The appearance of the undisturbed sediment was a loose grey gel.

Gasoline, petroleum solvents, fuel oil residues, total PCB's and cyanide within the sediment samples were all at concentrations below detection limits. Data on metals and nutrient content of the sediment are provided in Appendix I. Zinc, lead, cadmium, loss on ignition, Kjeldahl nitrogen and phosphorus values were found to exceed provincial guidelines for open water disposal of dredged materials (MOE 1991a). Sediment selenium concentrations at the deep sample site exceeded the guideline for agricultural / residential/parkland disposal (MOE 1991a). In other words, dredged material from Puslinch Lake is clearly not suitable for disposal within a section of the lake itself or any other open body of water, and it is unlikely that dredged material from the lake could be spread on farmland. More sediment samples should be taken to verify the extent and amount of metals contamination, particularly if dredging activity is to take place.

Hans et al. (1981) recorded lead levels of 56.9 and 90.7 mg/L (ug/g) in the sediment at two nearshore sites at Puslinch Lake. Their values fall within the range presented in Appendix I.

5. Macrophytes

There is a general perception that there are too many macrophytes on Puslinch Lake (Whitehead 1980). Macrophyte cover at Puslinch Lake, however, varies greatly from year to year. The plants are so dense some years that ski boats "plow" a path clear (tear up plants with their propellers) for ski runs. During other years the lake water is more turbid and macrophytes do not develop as extensively, presumably due to the shading effect of the murky water.

Two surveys of lake macrophytes were performed in 1987. The results of that study are reproduced as Appendix II. Only minimal macrophyte cover was noted and water clarity was low. The spring crop of Potamogeton crispus had died back by the time the surveys were conducted. Potamogeton amplifolius, Myriophyllum spicatum and Chara were dominant during the surveys.

6. Fish Populations

An account of the local plant, bird and fish populations is given by Hans et al.

(1981). Largemouth bass were present in the 1930's and the lake was stocked with walleye, smallmouth bass and muskellange from 1940 to 1960 (Hans et al. 1981). None of those three species has fared very well at the lake, partly due to poor habitat, an unplanned introduction of pike and fish kills in 1953 (winter), 1960 (winter), 1967 (summer), and 1978 (winter). Creel census data indicate more abundant fish in 1961 than in 1980 (Hans et al. 1981). M.N.R. did gill and seine net studies in 1987 to determine the status of the fish community. Very few adult bass, perch, sunfish and rock bass were captured. Pike were more numerous than other species and were all young - representing a population that was still recovering from the last fish kill. Walleye were reproducing in small numbers. Growth rates of all juvenile sportfish (esp. perch, bass, sunfish) were very low, suggesting an inadequate food supply of invertebrates (Craig Selby and Larry Halyk, MNR Cambridge, pers. comm.).

7. Questionnaire Surveys

MOE first became involved with Puslinch lake in the early 1970's. It soon became clear that lake use and management were divisive issues within the local community. A variety of groups existed with conflicting interests. For example:

A) World class ski teams used powerful boats on ski runs along the north side of the lake. Other groups did not want power boats on the lake at all and preferred canoes, row boats or sail boats only.

B) Some groups wanted to improve the lake's fish populations and attract more day trip fishermen to the lake. Others felt that fishermen were noisy and left too much garbage behind while adding little to the local economy.

The major rift in the local population was between the factions advocating commercializing the lake's resources and attracting widespread public use versus those wishing to reduce public use and maintain the lake as a quiet private hideaway for local land owners. It was concluded that a firm consensus on the management and uses of Puslinch Lake was required before the lake could be rehabilitated (Archie McLarty, MOE Hamilton, pers. comm.).

The first opinion survey was initiated by the Township of Puslinch (Whitehead 1980). Cottagers ranked water pollution, increase of aquatic vegetation, inadequate private sewage treatment and boating and water skiing as major concerns.

The Township of Puslinch then retained Jean Monteith and Associates Ltd. in 1984 to distribute a mail-in questionnaire on lake use and regional issues to local residents. In this second survey, the residents were quite evenly divided on who should use the lake for recreation (local versus outside population) but were generally against further recreational development on the lake. In contrast, they favoured more residential development around the lake, including the conversion of seasonal residences to year round use and placing additions on homes on undersized lots. The residents clearly

wanted regular inspections of wells and septic systems along with boating controls on the lake.

The Puslinch Lake Property Owners Association (PLPOA) was started in 1981 to coordinate various interest groups on the lake. The PLPOA was instrumental in having Puslinch Lake become part of the MOE Inland Lakes program in 1987. In June of that year, representatives of the PLPOA, MNR, MOE and GRCA decided to resurvey lake residents regarding their preferences on lake use. A survey was produced and distributed by the PLPOA in August 1987. The survey was issued in two parts, one for the local residents and one for the public or visitors. The results of the survey are presented in Appendix III. The responses were quite similar to the earlier surveys, with lake water quality, lake weeds, fishing and swimming heading the list of unsatisfactory items at the lake.

8. Lake Rehabilitation

In early 1988, we planned for the limnological rehabilitation of Puslinch Lake. The physical and chemical nature of the lake limited the options for whole lake treatments to improve water quality. Hypolimnetic aeration would serve no purpose as the lake was shallow and had only a small deep water area (Fig. 1) and there was enough wind mixing (a polymictic situation) to preclude the need for artificial destratification as well. At the time, drawdown to allow sediments and macrophytes to

dry up for easy removal looked attractive but the lake may not have filled up quickly again given the lack of a defined inflow and a relatively small watershed (we now know that the lake flushes about once a year, however, see results section). Sensitive marshland around the lake may have been damaged by a drawdown scheme as well. Similarly, there did not seem to be a sufficient reserve supply of local water to actively flush the lake to improve water quality. Bottom sediments were too flocculant to seal off and large-scale dredging was prohibitively expensive. In any case, the potential metals contamination described above would have made disposal of dredged material a difficult and costly proposition. It would not be possible to simply dispose of the material on farmland.

The expressed concern of residents over excessive macrophyte growth at Puslinch Lake (see above) led to the misguided notion that macrophytes per se were the problem. Macrophytes are not a water quality problem; they are merely a symptom of lake conditions in general. It is a far better situation to have many macrophytes and clear water in a lake than just a few macrophytes and murky green water because of phytoplankton and resuspended sediment. It was not advisable to harvest macrophytes extensively around the lake to "improve" water quality for several reasons:

1) When macrophytes naturally die back and rot they do not always release appreciable amounts of phosphorus back into the water. The notion that macrophytes move large amounts of phosphorus back into the waters of Puslinch

Lake when they die off has perhaps been given undo emphasis in previous studies. Most of the phosphorus in the leaves of P. crispus does not immediately return to the lakewater when the plants die in Rice Lake (MOE, unpublished). M. spicatum on the other hand, does release some phosphorus back into the water column during senescence (Landers 1982).

2) When harvesting healthy, growing macrophytes and removing them from a lake, the phosphorus held in that tissue is removed from the lake as well. The amount of phosphorus removed is usually minimal, however, compared to the amount of phosphorus held by the lake's sediment.

The early summer biomass of macrophytes (excluding Chara) in Puslinch Lake in 1987 held about 21 kg of phosphorus (Appendix II). If one includes all of the macrophytes and Chara the amount becomes approximately 80 kg P (calculated from Appendix II data). The average phosphorus concentration in the sediment was about 0.8 mg/g as P (calculated from Appendix I data). If one assumes that this flocculent sediment is 95% water with about the same density as water then 1 cm^3 of sediment yields 0.05 g dry wt. sediment, equivalent to 0.04 mg P. Conservatively estimating an even 1 m deep layer of this sediment throughout the surface area of the lake (approx. 160 ha), one arrives at a figure of

1.6 X 10^{12} cm^3 of sediment. That volume of sediment is equivalent to 6 X 10^4 kg of phosphorus. The mass of phosphorus held by the sediment is about 100 times that held by the macrophytes.

3) A lake ecosystem is not enhanced by removing its macrophytes. Macrophytes help to stabilize sediment and offer refuge and food for fish and invertebrates which can act to reduce phytoplankton densities and keep lake water clear (e.g., Ozimek et al. 1990). When macrophytes are removed all of that protection is lost and the scene is set for turbid, green water.

It is simply bad lake management practice to remove extensive amounts of macrophytes from a lake for phosphorus control. In the case of Puslinch Lake, years with "excessive" macrophyte cover may represent a healthier situation than years with few macrophytes and a dominance of turbid green water. Some harvesting to produce channels in dense macrophyte stands may help fisheries habitat by producing more "edge" for foraging fish.

In early 1988, it was decided that some form of chemical treatment would be the best alternative for Puslinch Lake. Alum was too expensive and potentially toxic and calcium nitrate or calcium hydroxide treatments were considered to be too severe. Calcium carbonate (powdered limestone) application seemed innocuous and good results had been obtained by Ellie Prepas at the University of Alberta at the time. On April 26,

1988, Dr. Prepas visited Puslinch Lake and reviewed some water quality data with the senior author. In consultation with Dr. Prepas, a 50 mg/L $CaCO_3$ dosage rate was determined sufficient to improve lake water quality.

MATERIALS AND METHODS

1. Outflow Monitoring

In 1989, the northern outflow of Puslinch Lake (two culverts under Townline Road) was gauged in order to monitor seasonal outflows. Staff gauge readings were calibrated to discharge rates via measurements taken by Teledyne Gurley meter and Montedoro Velocity meter (Plazek and Elias 1990). A logarithmic regression was applied to the calibration data to obtain the following relationship:

Gauge level in cm = 83.841 + 11.9678 (ln Q)

where Q = discharge rate in $m^3 \cdot s^{-1}$

The R square for the equation was 0.994. Routine gauge measurements were made by Hilton Lyons (Cambridge Fish and Game Protective Association) in 1989 and 1990.

2. Water Chemistry, Phytoplankton and Zooplankton

Most samples were collected from a main station directly above the deepest part of the lake off McCormick's Point (Fig. 1). The sampling schedule is outlined in Table 1. The lake was sampled from 1987 to 1990. Standard Secchi disc depth readings were taken during each visit to the lake. A YSI Model 58 dissolved oxygen and temperature meter was used to obtain temperature and dissolved oxygen profiles at the station. Oxygen measurements were verified with the azide modification of the Winkler titration

technique (APHA et al. 1976) after modification for small (60 mL) sample size on samples of surface and bottom water. Water samples were collected one meter off bottom (1 MOB) using a 6 litre PVC Van dorn bottle. Euphotic zone composite samples were taken by lowering and raising two weighted, narrow mouthed (2.1 cm diameter) 1 litre glass bottles through the euphotic zone so that they filled just as they reached the surface. The euphotic zone was defined as twice the observed Secchi disc depth to a maximum depth of 1 meter off lake bottom. During each site visit, one euphotic zone sample was collected from each of three stations (West, East and Main, see Fig. 1). The three samples were then mixed in a bucket in order to be representative of the entire lake area. A portion of the mixed euphotic zone sample was then removed (500 mL) for phytoplankton enumeration (preserved with 2 mL of Lugol's solution). Another 500 mL of mixed composite sample was removed for chlorophyll analyses and buffered with 2 mL of a 2% by weight $MgCO_3$ solution (to help prevent degradation of chlorophyll pigments). Two subsamples (500 mL each) were taken from both the 1 MOB and mixed composite water samples for chemical analyses and trace metal analyses. The trace metal subsamples were preserved with 1 mL of concentrated nitric acid to prevent precipitation.

Zooplankton samples were taken with a Clarke-Bumpus net (80 μm mesh, 12.3 cm diameter aperture) adapted for short vertical hauls with a sensitive flow meter. For

each sample, the net was towed vertically from 1 MOB to the surface and then a second haul was made over the same distance with the net removed in order to calculate collection efficiency. Zooplankton samples were preserved with 4% sugared formalin.

All water chemistry analyses were performed by the Ontario Ministry of the Environment Rexdale Laboratory using their standard methods (MOE 1991b). Phytoplankton analyses were made using settling chambers and inverted microscopes for counting and obtaining dimensions. Volume formulae used by the Aquatic Plant Unit were used to create biovolume data (MOE 1991c). Zooplankton analyses were performed using the ZEBRA automated system to calculate length vs. weight relationships. The method is described in Yan and Mackie (1987)

3. Calcium Carbonate Application

A specially designed barge was used to apply 76.4 metric tonnes of calcium carbonate (as powdered limestone) in a slurry form on the lake's surface over three days (September 7, 8 and 9, 1988). All areas of the lake deeper than 1 m were covered except for a 30 m wide strip around all shoreline areas (including islands) at an even dosage rate of 50 mg/L. With this concentration based application rate, deeper areas of the lake received more calcium carbonate per unit area.

The characteristics of the limestone powder used are presented in Table 2. The

barge was 9.4 m long and 4.3 m wide with its stability pontoons extended outwards (Fig. 2). While docked at shore, the barge took on lake water in a special tank in the hull. The tank's capacity was 6 m^3. Powdered limestone from bulk pneumatic hopper trucks (Fig. 3) was then blown into the chamber while a centrifugal pump mixed the powder into a slurry. Spray arms extending to a 18.3 m width off of the stern of the barge were used to distribute the slurry over the surface of the lake (Fig. 4). The dosage rate was controlled by an on board computer (Fig. 5) and a sensitive shore based guidance system (LORAN type) which accurately (± 0.5 m) positioned the barge on the lake's surface. Water depth, barge speed, dose rate, width of spray and slurry solids level were monitored to control application rate. An Agriculture Canada permit was required to apply calcium carbonate to Puslinch Lake (research permit 236-RP-88).

RESULTS AND DISCUSSION

1. Lake Turnover Rate

The discharge results for Puslinch lake are shown in Fig. 6. The data for 1989 only cover the period April to August, from the tail end of the spring freshet through spring rainfall to summer drought. The cumulative discharge for that period amounted to 9.1×10^5 m^3. The 1990 data covered a wider time frame, from March to October. As a result, more of the spring freshet was measured than in 1989 and some of the fall rains were caught as well. The cumulative discharge observed in 1990 was 1.9×10^6 m^3.

The discharge rate for Puslinch Lake was surprisingly high considering the relatively small watershed area and no defined inflow. The cumulative discharge observed over eight months in 1990 is close to the total volume of the lake itself (approximately 2.3×10^6 m^3). It is reasonable to assume therefore, that Puslinch Lake has a normal turnover time of about one year.

Nitrate concentrations observed in the lake are presented in Fig. 7. Puslinch Lake had peak nitrate concentrations during spring freshet as is typical for lakes in Southwestern Ontario (Vandermeulen and Gemza 1991, Gemza 1991). The peak was missed in 1987 because sampling did not begin until mid May (Table 1) after most of the freshet had passed.

Puslinch Lake was unusual in having elevated mid summer concentrations of nitrate from time to time, particularly in 1989 and 1990 (Fig. 7). These summer nitrate peaks may be evidence of nitrate laden groundwater from beneath the lake entering the lake. Groundwater in the area typically has 8 mg/L nitrate (Bill Annable, Cumming Cockburn, pers. comm.). Groundwater springs have been suspected in the lake in the past (see Introduction) and their presence may help to explain why Puslinch Lake has a higher than expected flushing rate.

2. Temperature and Dissolved Oxygen

Fig. 8 is a record of temperature and dissolved oxygen concentrations. The lake did not form a strong stratification which remained intact over the summer months. During each year of the study, thermal stratification would develop in the deeper water off McCormick's Point along with bottom water anoxia and then a sudden mixing event would even out surface and bottom temperatures and raise the oxygen content of the bottom waters. These mixing events were likely wind driven (summer storms) and were a characteristic of the open water limnology of this broad, shallow lake.

3. Water Chemistry

Bottom water anoxia causes sediments to enter a reduced state which allows a variety of sediment bound hydroxide precipitates to dissolve. As a result, concentrations

of several metal ions then can increase in the bottom waters. Fig. 9 illustrates how iron and manganese concentrations increased in the bottom waters off McCormick's Point during times of anoxia (compare to Fig. 8). Surprisingly, orthophosphorus concentrations differed little between surface and bottom waters (Fig. 10), even during periods of bottom water anoxia. Internal phosphorus loading due to bottom water anoxia does not seem to be an important phenomenon in Puslinch Lake. Ammonium was released into the bottom waters during anoxia, however (Fig. 11). Mixing events would move this ammonium into the surface waters and the lake would act like a large nutrient pump from the bottom to the surface. Luckily, the total volume of the anoxic, ammonium rich bottom water off of McCormick's Point was small compared to the lake volume as a whole (Fig. 1) and ammonium concentrations did not rise in the surface waters after a mixing event (Fig. 11). Rapid absorption of ammonium by phytoplankton may have also dampened increases in ammonium concentrations in surface waters.

Nutrient concentrations were generally high in the lake waters. Total phosphorus values peaked at over 0.10 mg/L (Fig. 10) and Kjeldahl nitrogen values were consistently well above 2 mg/L (Fig. 12). The Total Nitrogen : Total Phosphorus ratio was extremely variable over time (Fig. 13) and illustrates the dynamic nature of nutrient cycling within the lake. It is very likely that nutrients in sediment pore waters are rapidly dispersed into the water column of shallow eutrophic lakes by wind mixing (DeGroot 1981, Bostrom et al. 1982, Shaw and Prepas, 1990). Therefore, even though anoxic internal loading may not be important in Puslinch Lake, the polymictic nature of the lake would still allow

sediments to be a potential source of internal nutrient loading (Ryding and Forsberg 1977). Sediment resuspension in shallow lakes is also a potential source of nutrients for the water column (Istvanovics 1988).

Dissolved inorganic carbon (Fig. 14), conductivity (Fig. 15), calcium (Fig. 16), alkalinity (Fig. 17) and hardness (Fig. 18) all followed the same pattern over time and indicate that the calcium ion/calcium carbonate system was important in Puslinch Lake. Marl deposits were commonly observed on macrophytes in the lake. Dissolved organic carbon values (Fig. 14) followed chlorophyll a trends (Fig. 23). pH of the bottom water was lowered (Fig. 19) during times of anoxia.

Turbidity (Fig. 20) and color (Fig. 21) were generally lower in the early spring clear water phase as is common in north temperate lakes. Both parameters increased as chlorophyll a increased (Fig. 23). Secchi disc depth (Fig. 22) was approximately 0.8 m during the spring clearwater phase (this phase was missed in 1987 because sampling did not begin until mid-May). Secchi disc depth very rapidly dropped to 0.4 m or less each year due to algae and resuspended sediment. Turbidity, color and Secchi disc depths were similar to those obtained in other eutrophic hardwater lakes in Southwestern Ontario (Vandermeulen and Gemza 1991, Gemza 1991).

4. Phytoplankton

Puslinch Lake was highly eutrophic and coupled with its well mixed, shallow morphometry, dense algal blooms appeared regularly. Soon after the early spring clear water phase, chlorophyll a concentrations rose to a peak of 70 μg/L or more each year (Fig. 23). In September 1990 values of over 110 μg/L were recorded. Total algal biovolume values were also high, particularly in 1987 (Fig. 24). Blue - green algae were an important component of the algal flora in the late summer and fall of each year (Fig. 24). A listing of dominant phytoplankton genera is given in Table 3.

As was typical for hardwater lakes in the region (Ontario Ministry of the Environment, unpublished data), different algal classes dominated in the lake during different years of the study. In 1987, chrysophycean species dominated for a brief time in spring while cyanophycean species increased in dominance right through to the fall (Fig. 25). Chlorophycean and bacillariophycean species maintained intermediate importance throughout the sampling period. In 1988, chlorophycean species dominated for most of the time and cyanophycean species did not take over until late summer and fall (Fig. 26). In 1989, bacillariophycean, cryptophycean and chrysophycean species consecutively peaked in abundance during spring and early summer (Fig. 27). Cyanophycean species peaked in summer while the chlorophycean species steadily increased in abundance during the entire sampling period. 1990 patterns (Fig. 28) were similar to 1987 without the spring dominance of chrysophycean species.

No major changes were noted in the generic composition of the seven algal classes monitored from year to year other than an abrupt change in Cyanophycean dominance from the first three years (1987 to 1989) when Aphanothece, Chroococcus and Lyngbya were dominant, to 1990 when Oscillatoria attained very high biovolume (Fig. 29).

5. Zooplankton

Zooplankters were not particularly abundant in Puslinch Lake. Total biomass values were 500 mg dry weight/m^3 or less for most of each sampling season (Fig. 30). In 1987, zooplankton were most abundant in early summer and then fell back to low biomass for the rest of the season as is typical for eutrophic hardwater lakes in the area (Vandermeulen and Gemza 1991, Gemza 1991). Zooplankton biomass in the other three years of sampling was quite variable and reflected the dynamic nature of Puslinch lake limnology. Herbivorous, large bodied Daphnia never dominated the zooplankton community for any length of time (Fig. 30). Cyclopoid copepods were spring dominants while non - daphnid cladocerans predominated during most of the summer and fall (Figs. 31 to 34). Low zooplankton biomass coupled with a low proportion of Daphnia indicate that this community had little ability to influence phytoplankton populations via grazing pressure.

6. The Effect of Calcium Carbonate Application

Calcite precipitation in hardwaters leads to the coprecipitation of phosphorus with a subsequent reduction in the concentration of phosphorus in the water (Jager and Rohrs 1990, Kleiner 1990). The natural precipitation process seems to work best in oligo- or mesotrophic lakes (e.g., Birdsey et al. 1984). High phosphorus concentrations in more eutrophic lakes can inhibit calcite precipitation (Kleiner 1988, Koschel et al. 1990).

A logical extension of the above information would be to apply an excess of calcium carbonate to a hardwater lake to externally alter and accelerate the rate of natural calcite/orthophosphorus coprecipitation and hence push the trophic status of the lake to a more mesotrophic condition. Indeed, laboratory experiments by Kleiner (1988) indicated that the addition of "seed" crystals of calcite to hypolimnetic water caused a rapid increase in the coprecipitation process.

Early whole lake applications of calcium carbonate for phosphorus control were conducted in Alberta. Researchers were encouraged by an early experiment (Prepas and Murphy 1987) and these results directly influenced the decision to apply calcium carbonate to Puslinch Lake. Unfortunately, subsequent research clearly indicated that calcium carbonate did not work as effectively as calcium hydroxide in reducing phosphorus concentrations and algal biomass in hardwaters (Babin et al. 1989, Murphy et al. 1990, Murphy and Prepas 1990).

Puslinch Lake did not show any dramatic response immediately after the calcium carbonate addition in early September 1988. Color, turbidity and pH increased after the calcium carbonate addition. Total alkalinity, calcium, hardness and DIC concentrations actually decreased after the $CaCO_3$ addition, as would be expected if a precipitation of calcite was being induced (Kleiner 1988). The same variables, however, also decreased during the same time frame in 1987. Jager and Rohrs (1990) stated that normal calcite precipitation occurs during fall overturn, which may explain the 1987 data. We could not find a consistent year to year relationship, however, between stratification and bottom water anoxia and alkalinity/hardness variables at Puslinch Lake.

No major changes in algal biovolume or species composition were correlated with the calcium carbonate addition except a slight but consistent reduction in total diatom biovolume (Fig. 35 A), although a similar drop in biovolume was also seen during the same time period during other years (Fig. 35 B). The sudden change in 1990 to Oscillatoria dominance in the Cyanophyte group (see above, Fig. 29) was not likely to be related to calcium carbonate application. Similar shifts in dominance have been seen in other lakes without chemical additions (Ontario Ministry of the Environment, unpublished data). No unusual or long term changes were seen in zooplankton abundance or diversity after the calcium carbonate addition.

No long term or delayed improvement of water quality was observed at Puslinch Lake even two years after the 1988 addition of calcium carbonate. Unusual water

chemistry conditions, however, were recorded on September 21, 1989 and June 14, 1990. Calcium, potassium, sulphate, conductivity, DIC, hardness and alkalinity all suddenly increased while chlorophyll a, DOC, total phosphorus, orthophosphorus and turbidity decreased. These changes may be related to the 1988 addition of calcium carbonate in some way but the link seems tenuous.

THE FUTURE OF PUSLINCH LAKE

The apparent failure of calcium carbonate to control phosphorus concentrations reopens the question of Puslinch Lake rehabilitation. A first step would be the implementation of a long term program of phosphorus loading controls including:

1) The control of gull and geese access to the lake. A "shoot to scare" program to harass gulls was attempted in the fall of 1990 (Roy Brown, PLPOA, pers. comm.). The approach may have merit. Birds should be frightened off of the site rather than destroyed. For example, large white swan decoys may cause Canada geese to avoid an area. Residents must bear in mind that Puslinch Lake is presently a wildlife sanctuary and migratory bird control is a Federal matter under the jurisdiction of the Canadian Wildlife service (Larry Halyk, MNR Cambridge, pers. comm.).

2) The elimination of septic inputs to the lake via the formation of a communal sewage treatment system with appropriate phosphorus precipitation and suspended solids disposal so that discharge waters have low phosphorus content. We would also strongly recommend regulating the density of development around the lake, using the concept of lakeshore capacity (Dillon et al. 1986).

3) An evaluation and treatment of non-point sources of nutrients in the watershed including land runoff and groundwater.

One cannot overemphasize the fact that a full scale phosphorus control program must be in place before any whole lake treatment is done. The program will require communal effort and expense while educating the users and residents on the need to maintain a clean watershed. Once a strong phosphorus control program is in place and operating smoothly, some form of whole lake treatment may still be required.

One potential source of nutrients for the lake is the historic phosphorus load bound up in the lakes surficial sediments. The sediments are already a likely active source of nutrients for the lake (see Water Chemistry section) and will remain so after other external sources of nutrients are controlled. The relative importance of nutrient loading from sediments is debatable, however, (Bostrom et al. 1988, Forsberg 1989), and far more extensive sediment chemistry work will be required at Puslinch Lake to determine if dredging has a good chance for improving water quality. Hydraulic dredging was not originally recommended due to the expense (millions of dollars) and potential difficulty in disposing of contaminated dredge materials. An engineering feasibility study would be required to explore the idea within the context of wetlands protection, macrophyte replanting, MNR and MOE approvals, and novel methods such as a partial drawdown of the lake to expose sediments for removal.

Lake rehabilitation methods are still in an experimental stage and there are no guarantees of success. Hardwater lakes in southern Ontario are naturally mesotrophic and, unfortunately, it does not take an inordinate amount of phosphorus loading to cause

them to become eutrophic. Broad, shallow lakes such as Puslinch Lake have a natural tendency to turn into wetland areas over time, and eutrophication accelerates that process. The sheer scale of the problem faced by the residents of Puslinch Lake is daunting - no matter which rehabilitation method they choose. There are no inexpensive, simple or easy solutions.

ACKNOWLEDGEMENTS

As always, Ken Nicholls has provided an environment which has been favourable for our study of lake restoration methods. His discussion sessions and advice have helped to direct this work from the start. The operators of Barbers Beach and McClintock's Marina provided boat access. Harry Stager coordinated the PLPOA questionnaire survey and did an exemplary job of running a series of public meetings on Puslinch Lake. Malcolm Stewart (Agriculture Canada) provided the calcium carbonate application permit under short notice. The Sweetwater Technology Corp. (Palmer, Pennsylvania) lime spreading barge was used. David Western (National Revenue) and staff evaluated the Sweetwater barge design and provided a temporary import permit to allow its use in Canada. Cliff Kearns (Employment and Immigration Canada) issued EMP 2151 work permits for the Sweetwater Technology staff.

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Table 1. Sampling dates for Puslinch Lake

1987	1988	1989	1990
	April 21	April 19	April 19
	May 4	May 4	May 3
May 12	May 18	May 16	May 15
May 29	June 1	May 29	May 30
June 9	June 15	June 14	June 14
June 23	June 20 June 22 June 30	June 26	June 25
July 7	July 13	July 11	July 11
July 22	July 27	July 25	July 25
August 5	August 10	August 8	August 8
August 21	August 22 August 24 August 26	August 21	August 22
September 2	September 13	September 5	September 6
September 17	September 15 September 21 September 30†	September 21*	September 17

* no phytoplankton sample for this date

† no zooplankton sample for this date

Table 2. Characteristics of the powdered limestone

ISO Sieve (μm)	Percent passing
600	100
300	99.9
150	98
75	90
45	80

Density	2.7 g/cm^3
Calcium carbonate	97 to 98.5%

Table 3. Dominant phytoplankton genera in Puslinch Lake.

Cyanophyceae	Dinophyceae	Cryptophyceae	Euglenophyceae	Chrysophyceae	Chlorophyceae	Bacillariophyceae
Aphanothece	Peridinium	Cryptomonas	Euglena	unidentified spp.	Scenedesmus	Synedra
Chroococcus	Gymnodinium	Katablepharis	Phacus	Chrysochromulina	Cosmarium	Melosira
Lyngbya	Ceratium	Rhodomonas	Lepocinclis	Chromulina	Chlamydomonas	Cyclotella
Microcystis	unidentified spp.		Trachelomonas	Mallomonas	Gloeocystis	Rhizosolenia
Oscillatoria				Codonocladium	Oocystis	Nitzschia
Anabaena				Salpingoeca	Tetraedron	unidentified spp.
Aphanizomenon				Kephyrion	Pediastrum	Navicula
Merismopedia				Bitrichia	Coelastrum	Fragilaria
Coelosphaerium				Centritractus	Botryococcus	
				Chrysosphaerella	coccoid sp.	
				Uroglena	Spondylosium	
				Synura	Staurastrum	
					Sphaerozosma	
					Monoraphidium	
					Stichococcus	
					Closterium	
					Golenkinia	

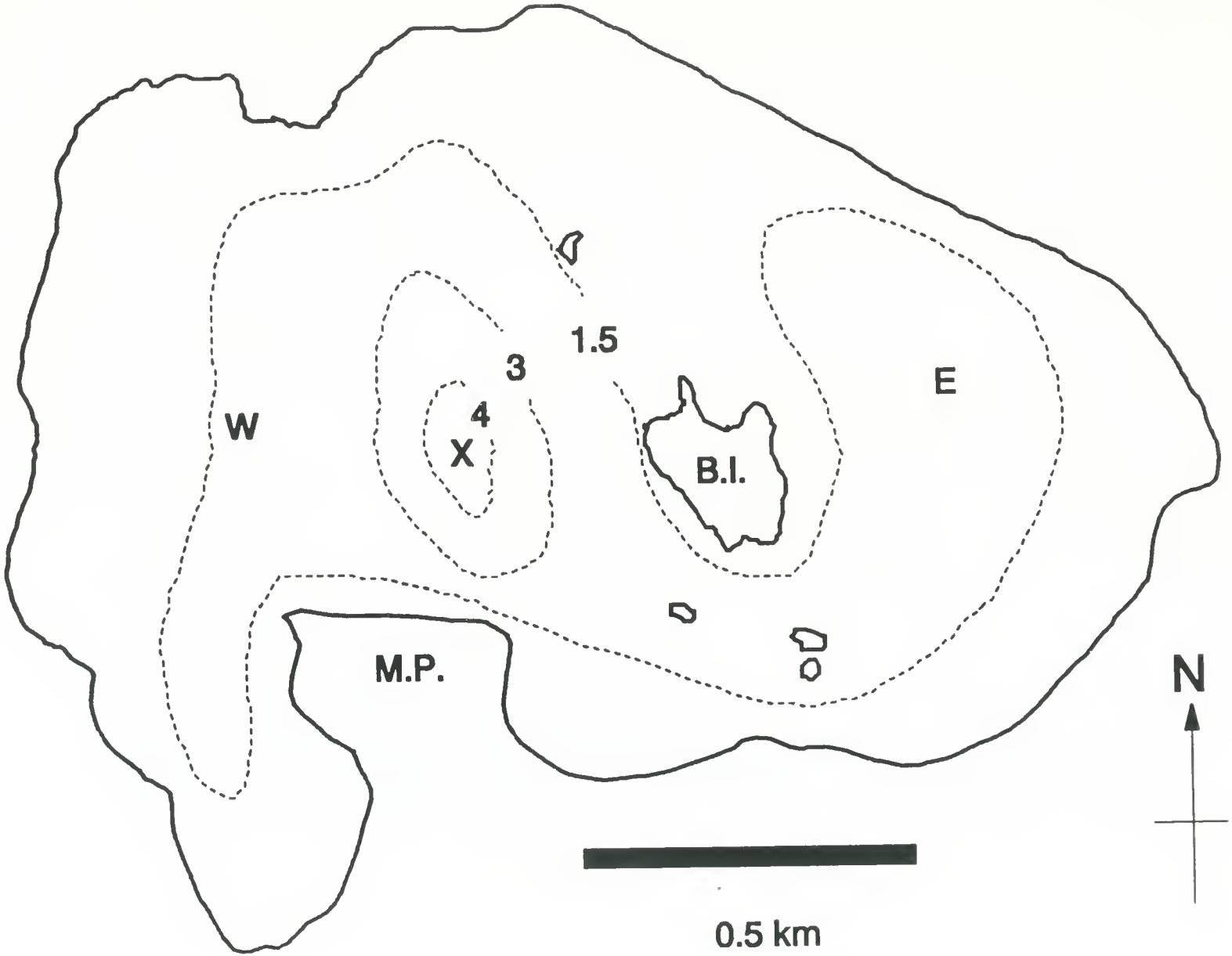


Fig. 1

Fig. 2

Fig. 3

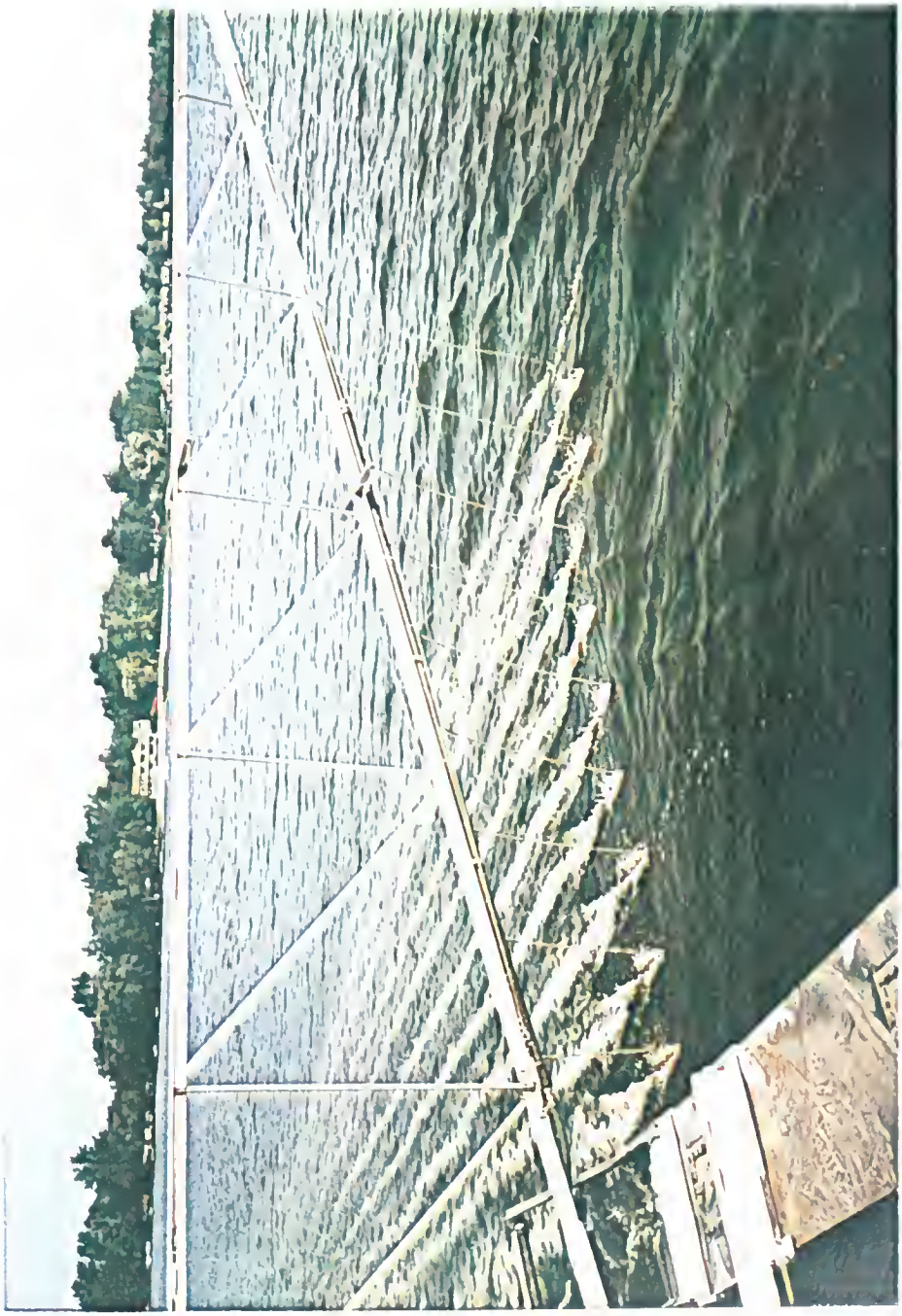


Fig. 4

Fig. 5

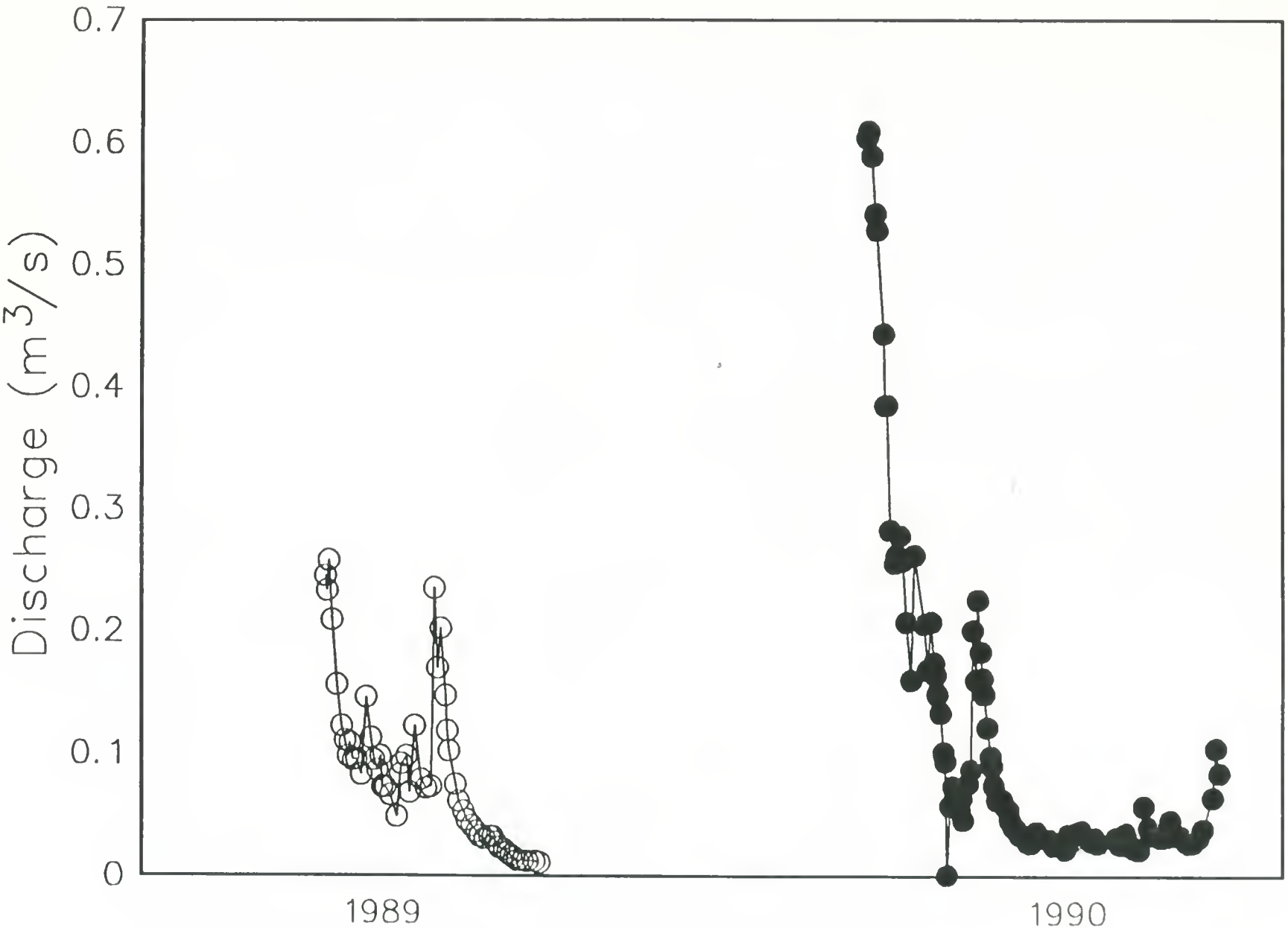


Fig. 6

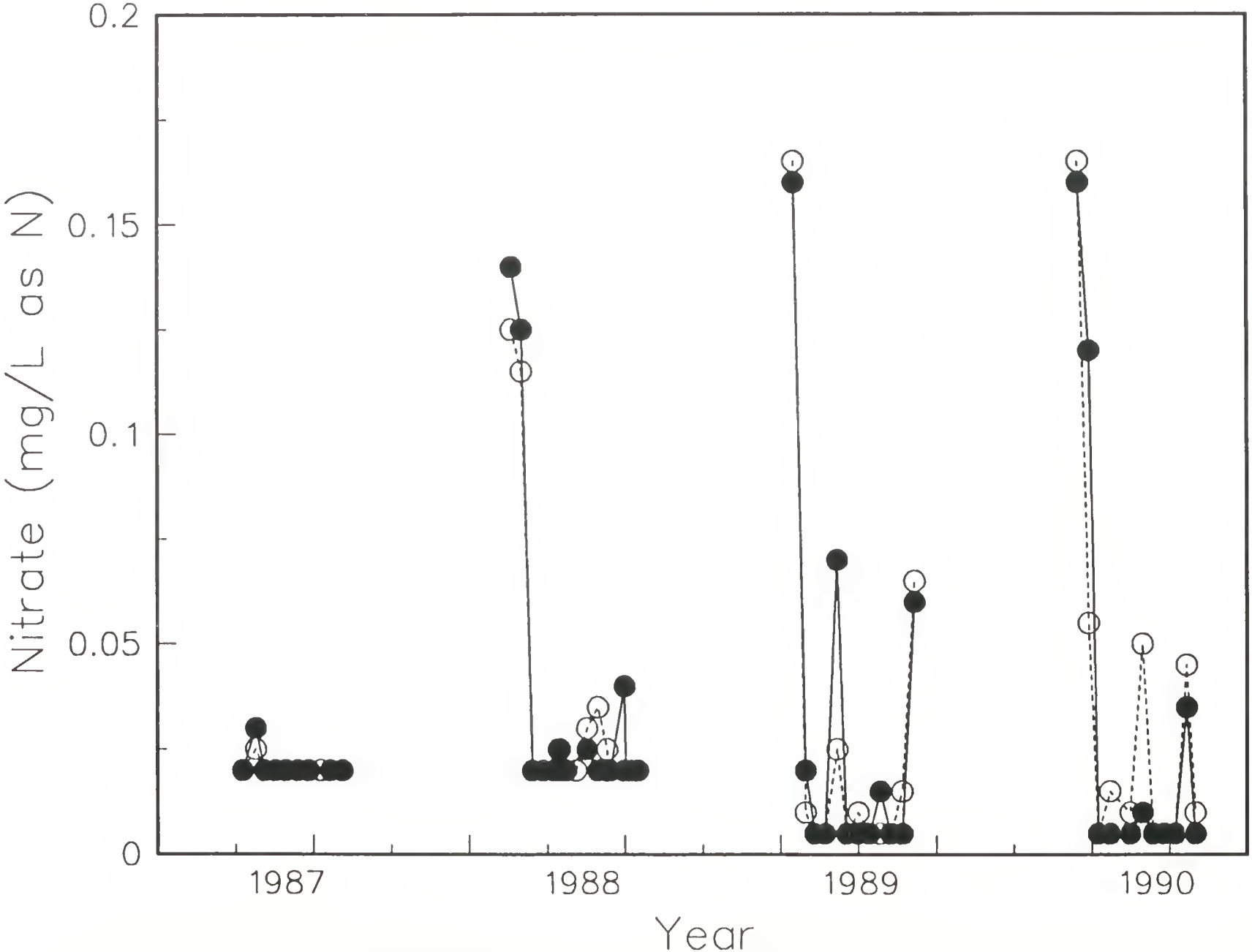


Fig. 7

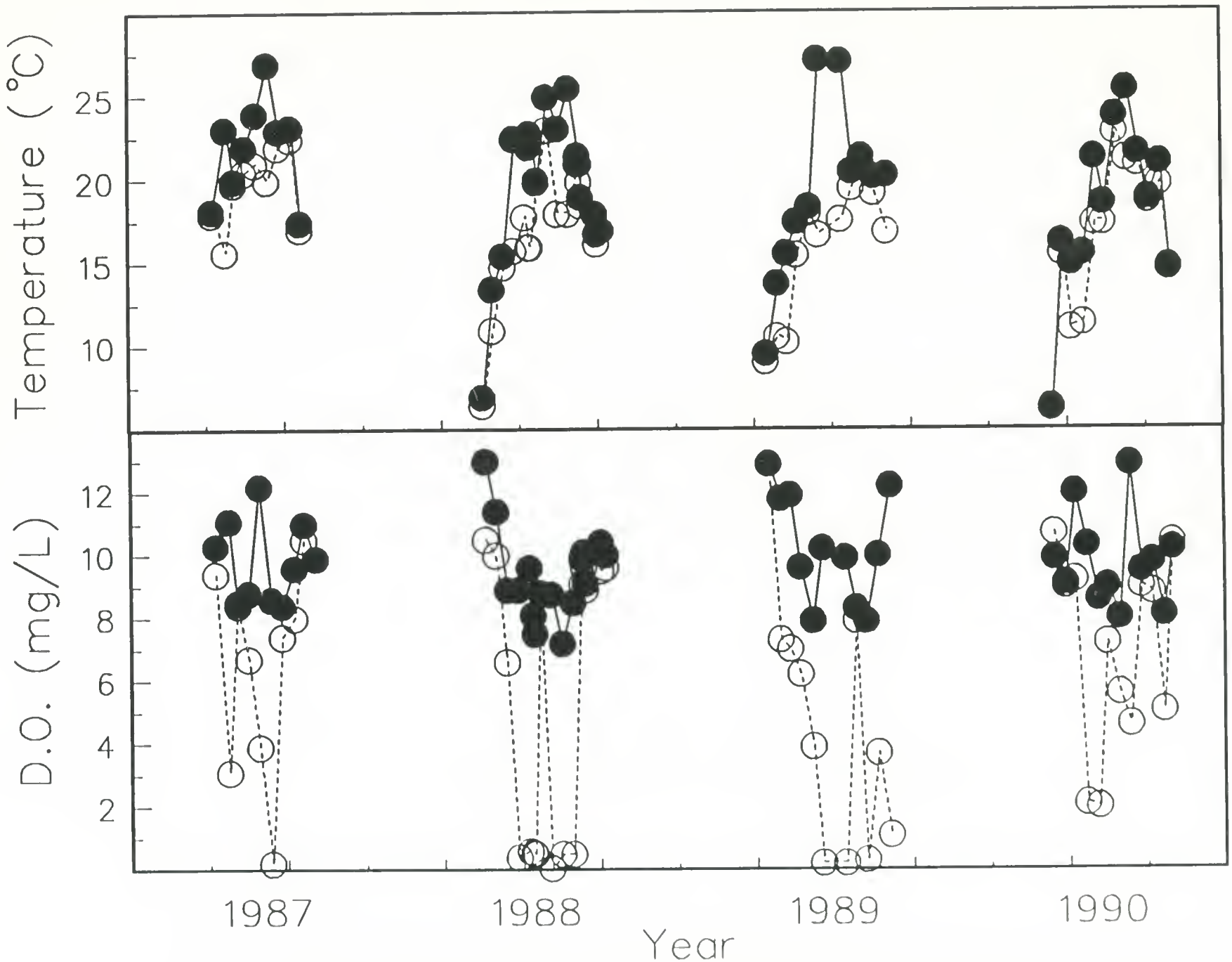

Temperature (°C)
25
20
15
10
D.O. (mg/L)
12
10
8
6
4
2
1987
1988
1989
1990
Year

Fig. 8

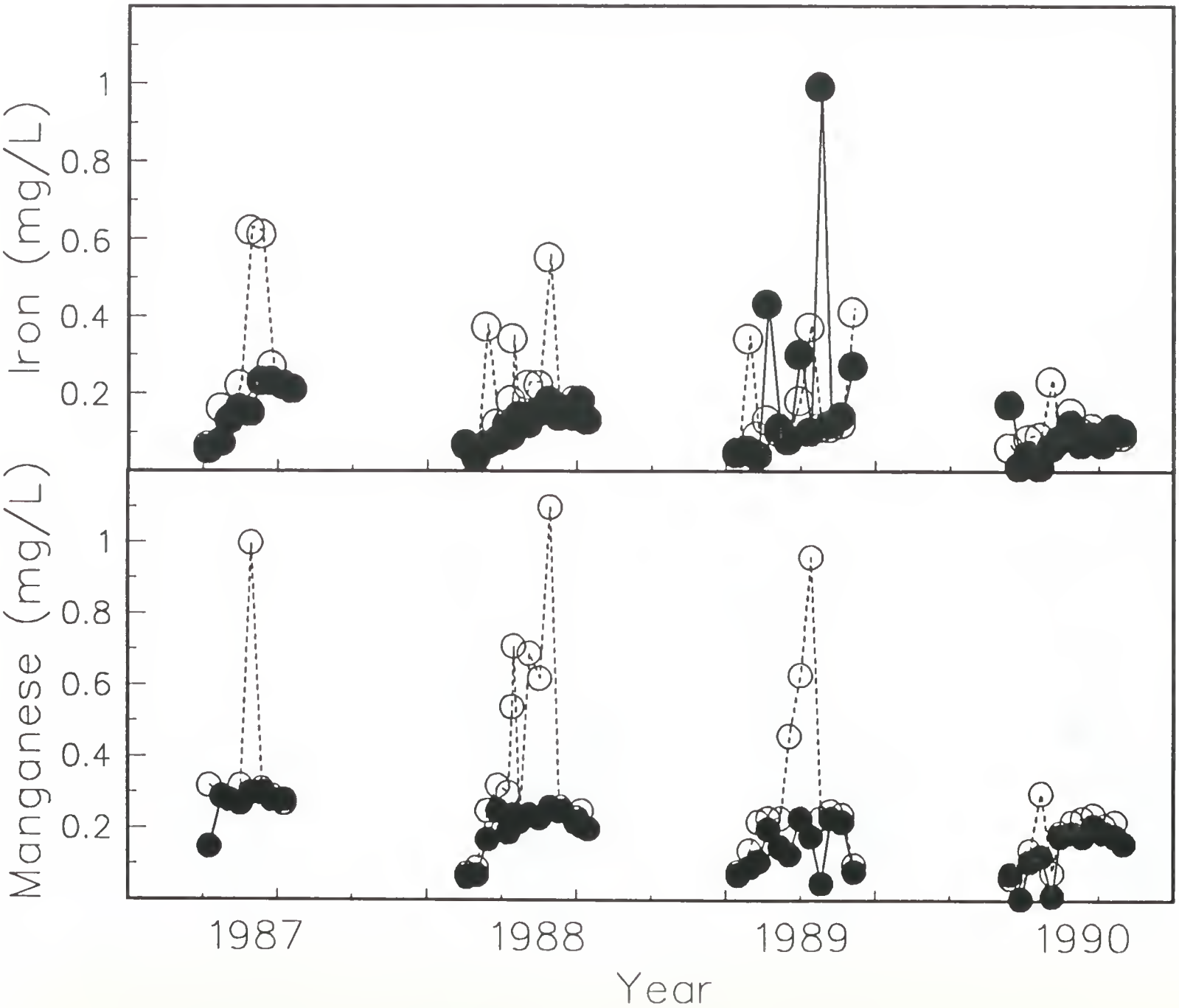

Iron (mg/L)
1
0.8
0.6
0.4
0.2
Manganese (mg/L)
1
0.8
0.6
0.4
0.2
1987
1988
1989
1990
Year

Fig. 9

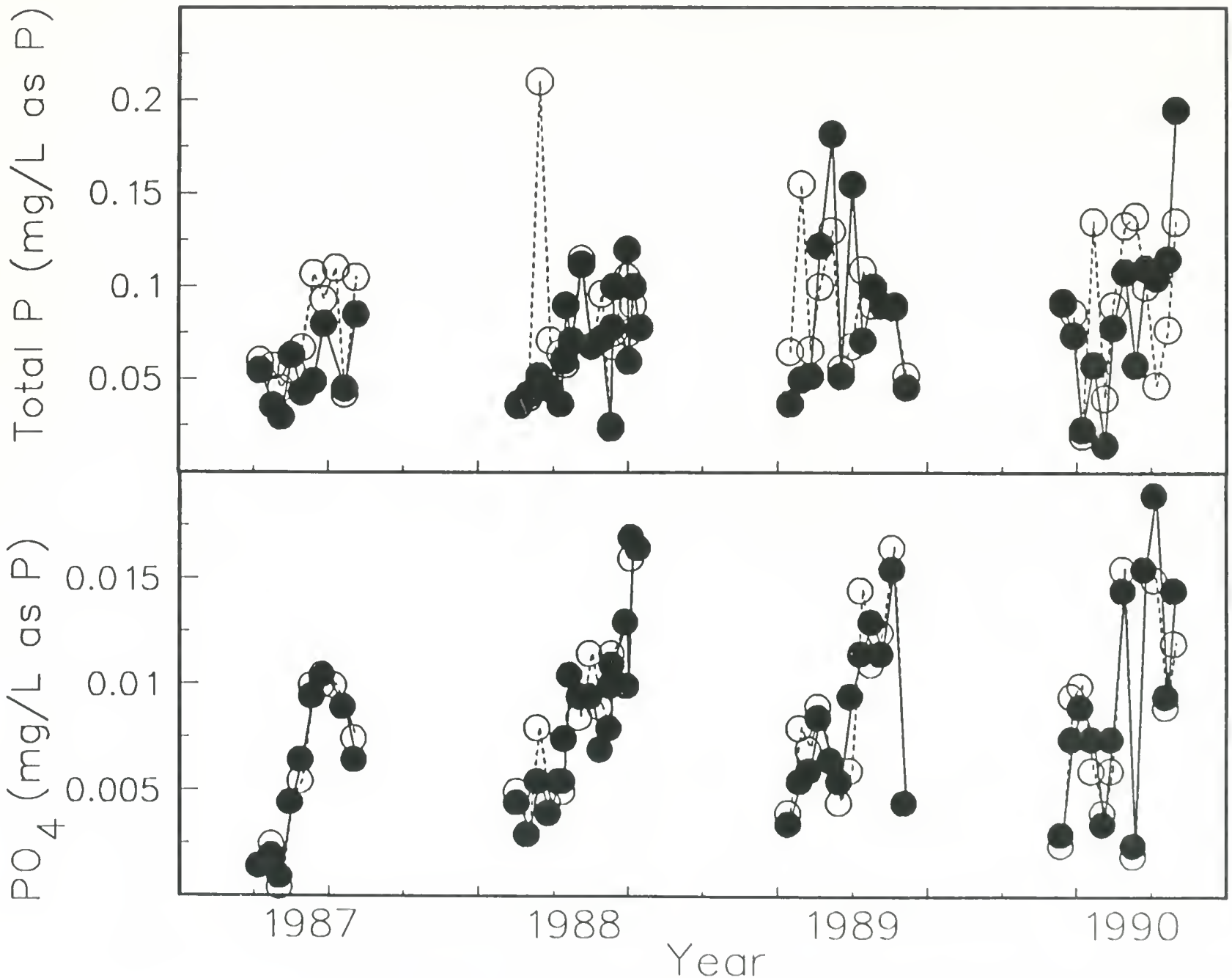

Total P (mg/L as P)
0.2
0.15
0.1
0.05
PO_4 (mg/L as P)
0.015
0.01
0.005
1987
1988
1989
1990
Year

Fig. 10

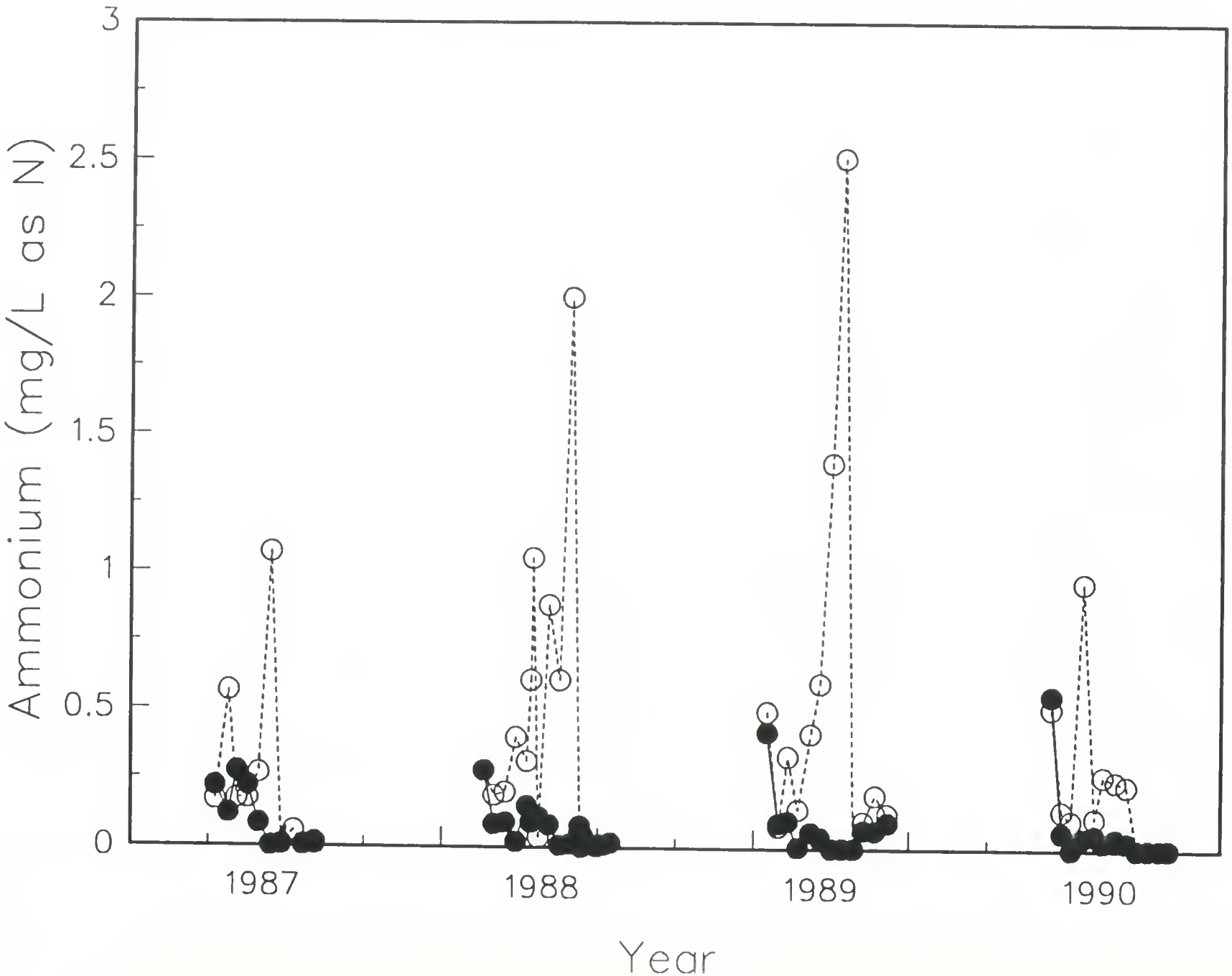


Fig. 11

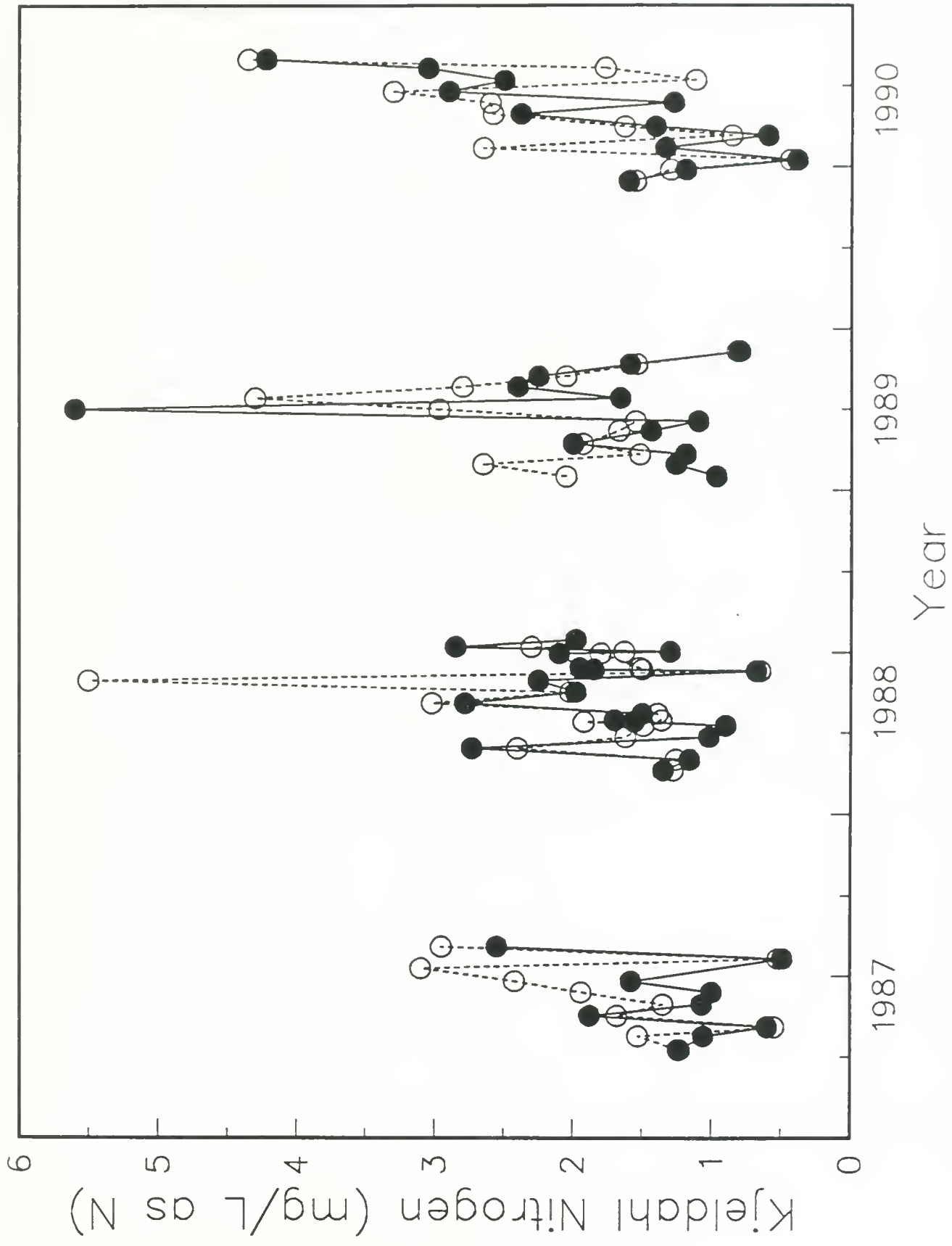


Fig. 12

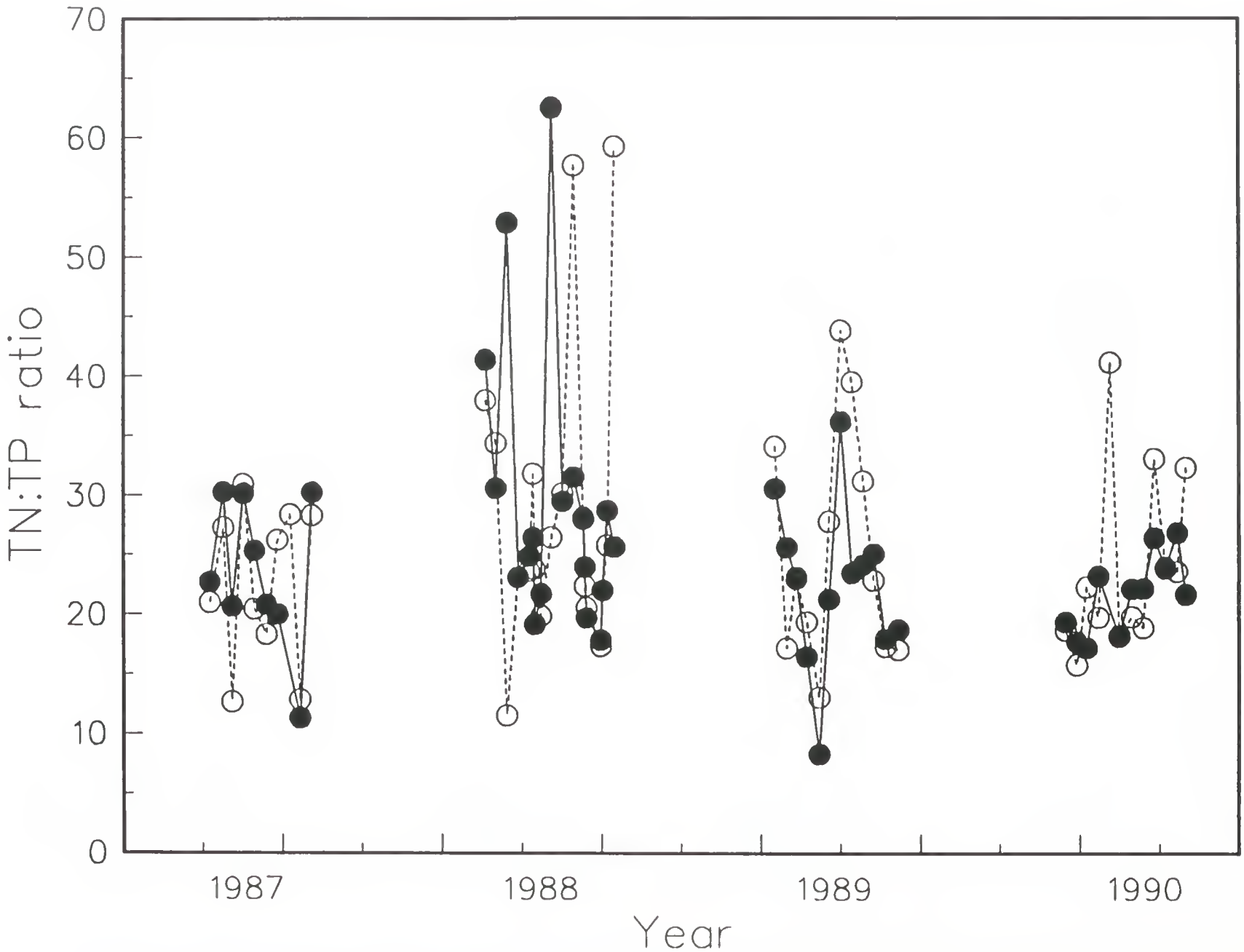


Fig. 13

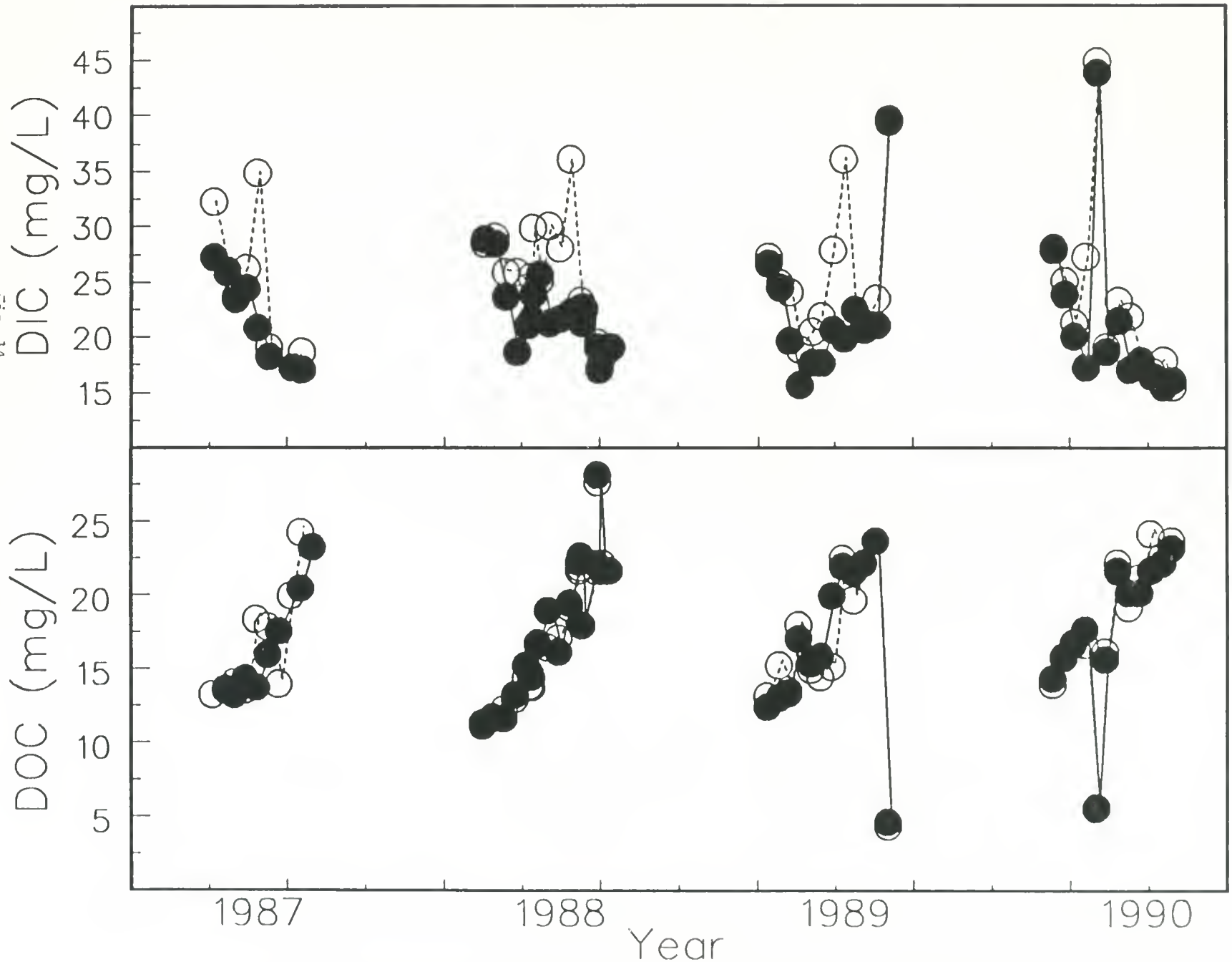

DIC (mg/L)
45
40
35
30
25
20
15
DOC (mg/L)
25
20
15
10
5
1987
1988
1989
1990
Year

Fig. 14

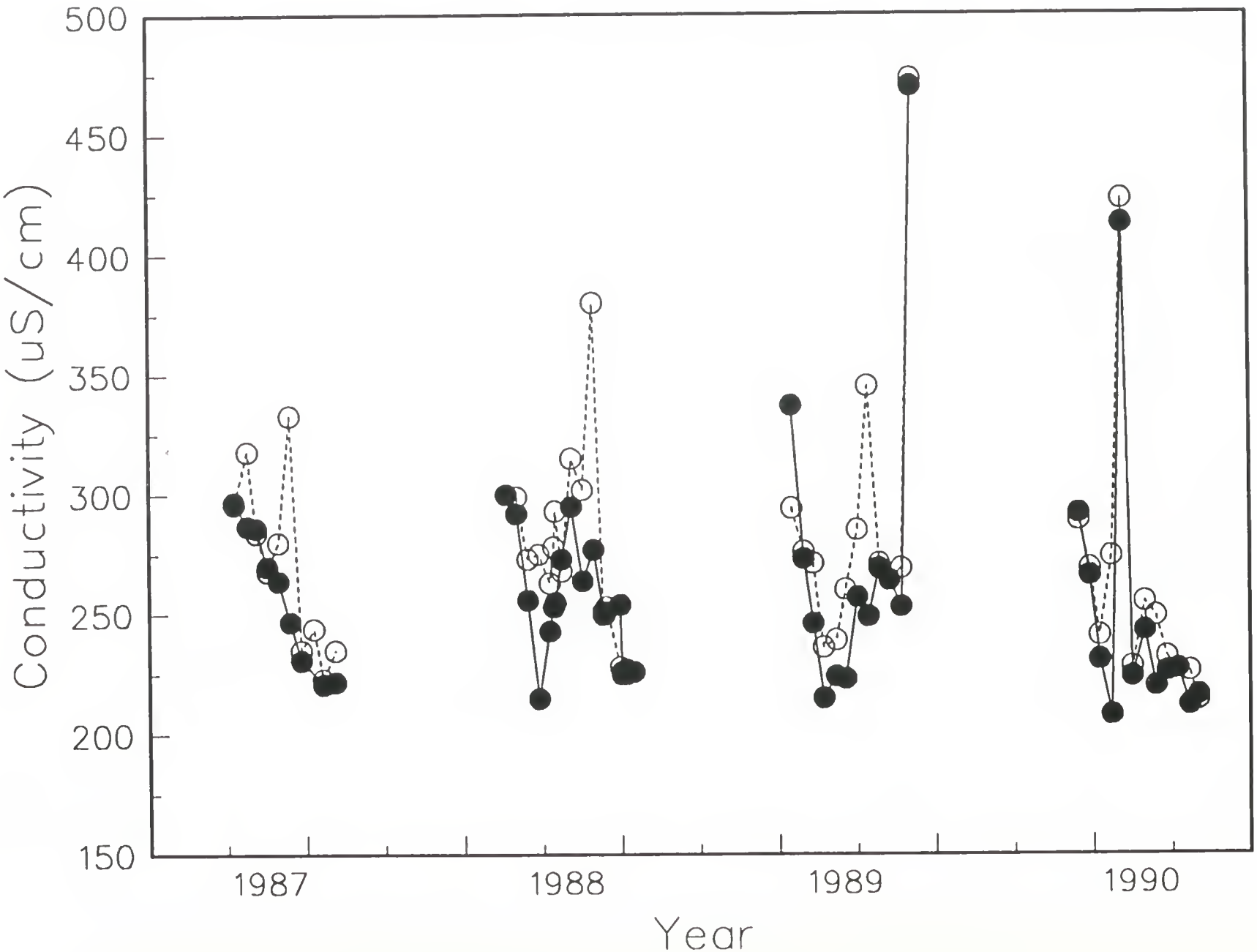

500
450
400
350
300
250
200
150
Conductivity (uS/cm)
1987
1988
1989
1990
Year

Fig. 15

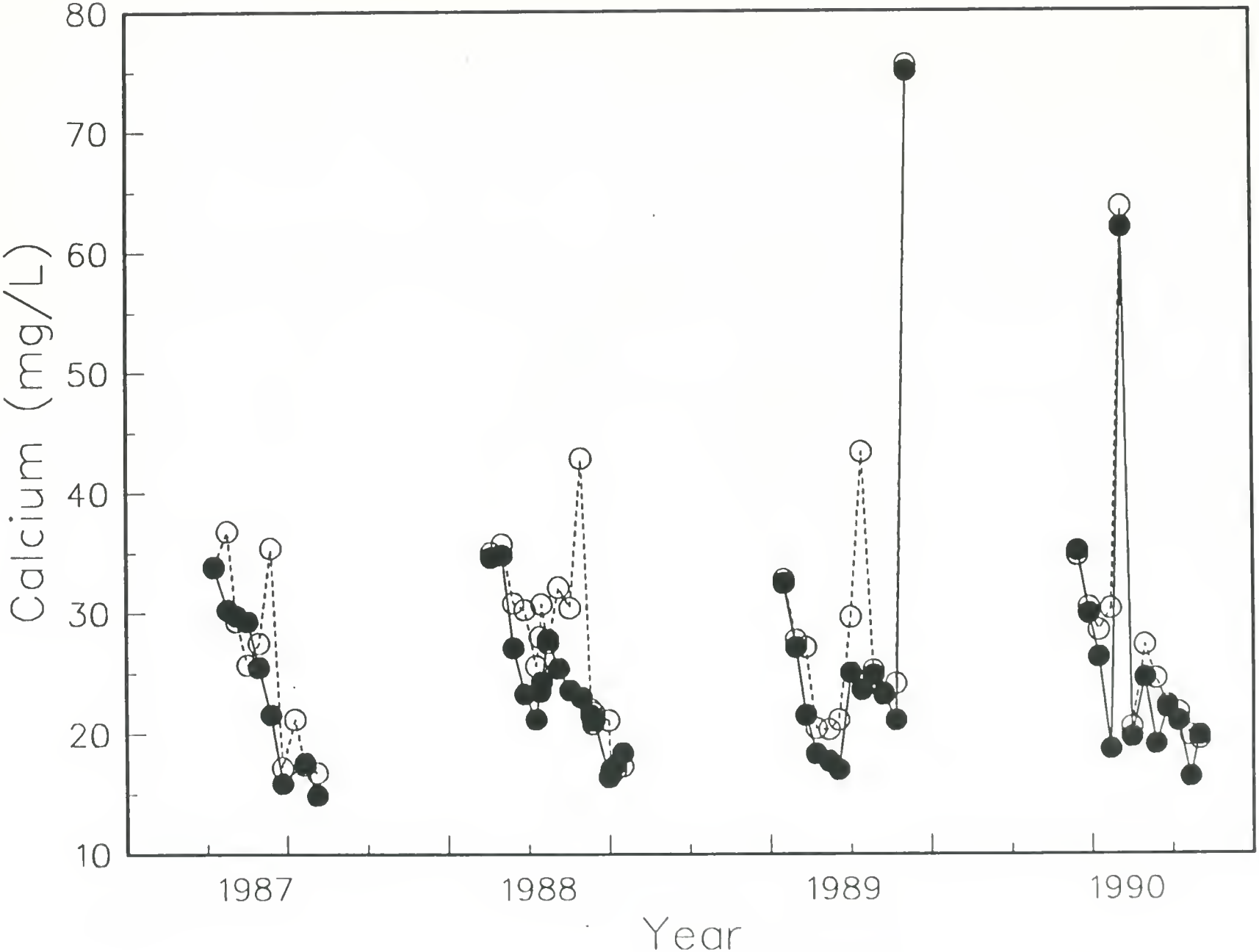


Fig. 16

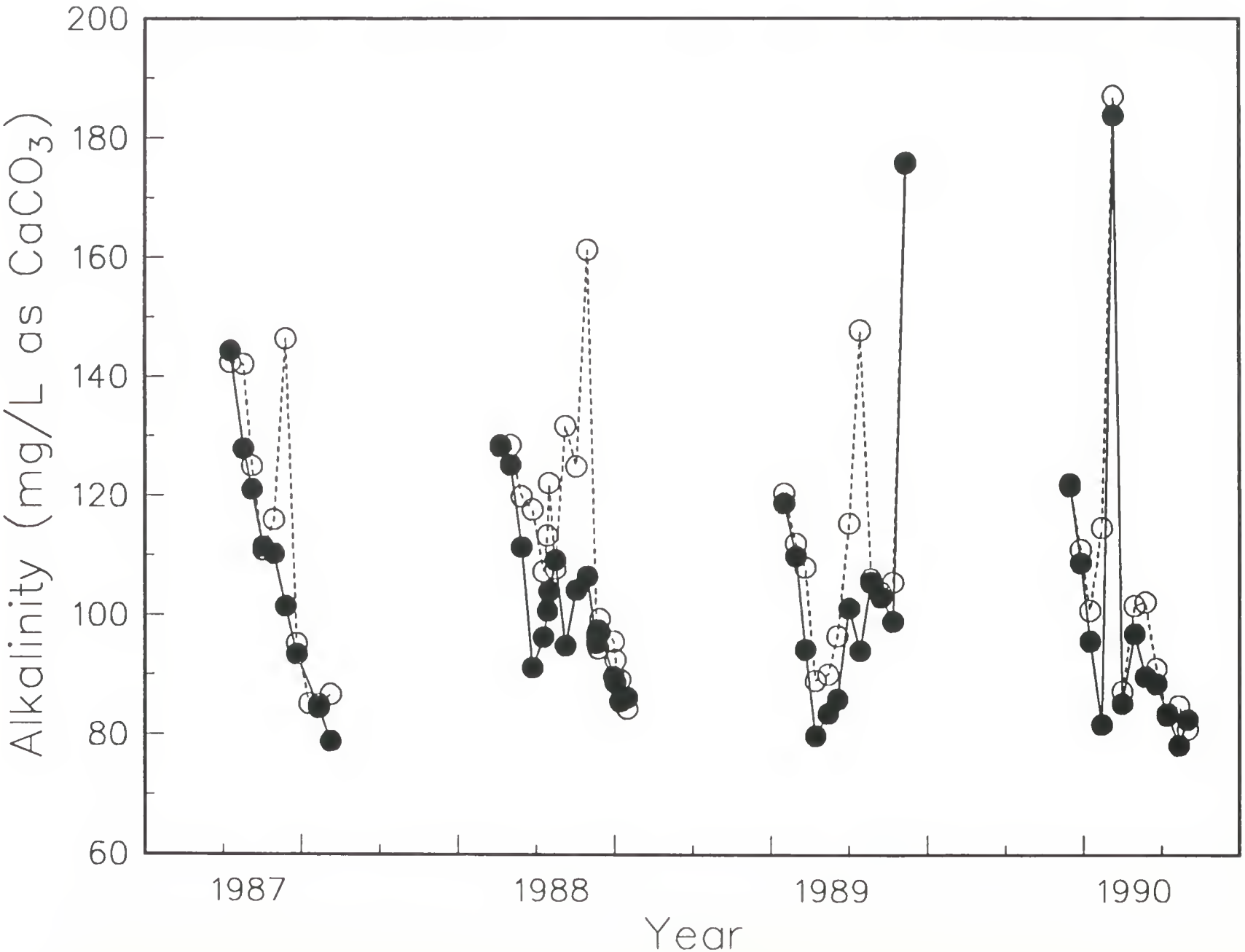

200
180
160
140
120
100
80
60
Alkalinity (mg/L as $CaCO_3$)
1987
1988
1989
1990
Year

Fig. 17

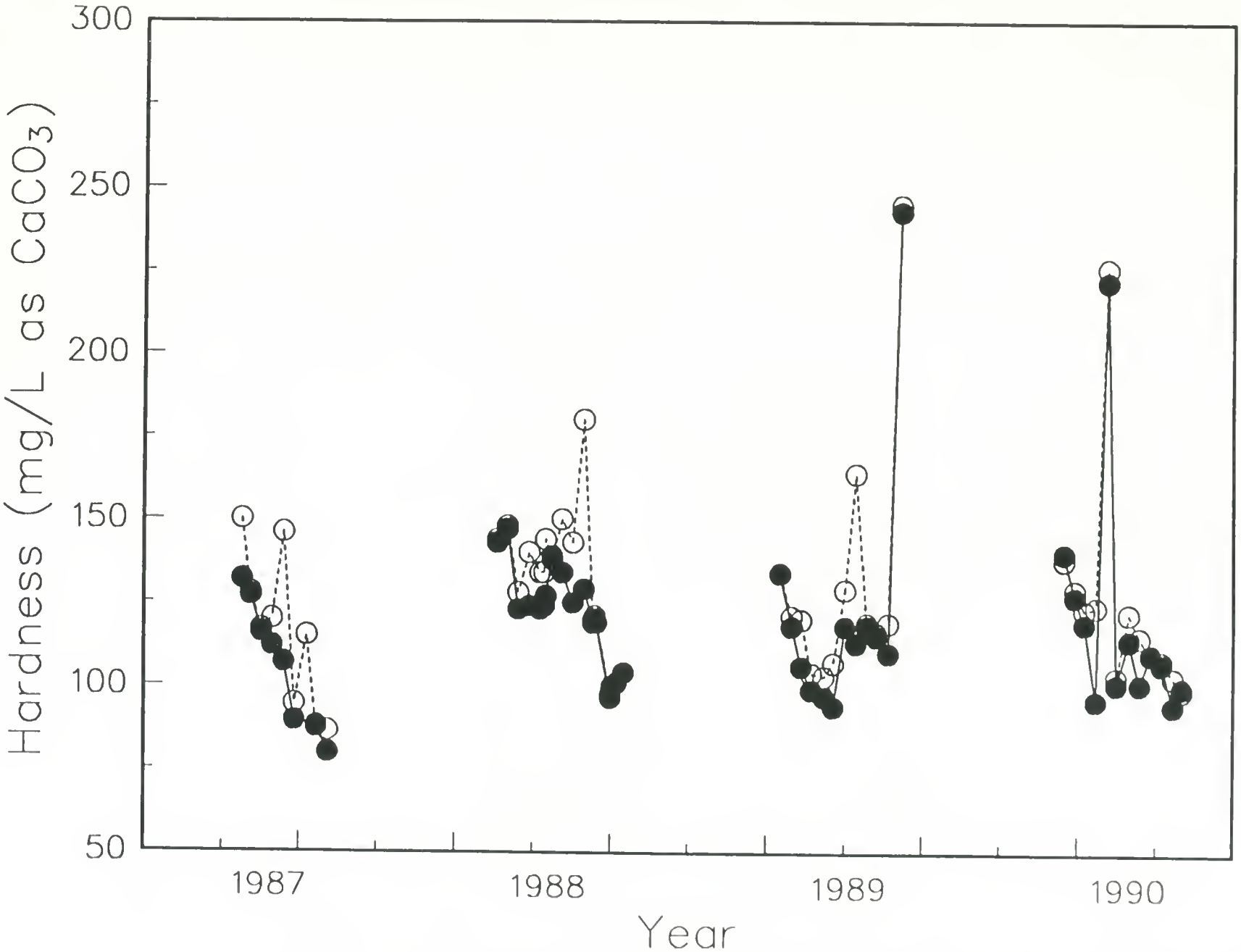

300
250
200
150
100
50
Hardness (mg/L as CaCO3)
1987
1988
1989
1990
Year

Fig. 18

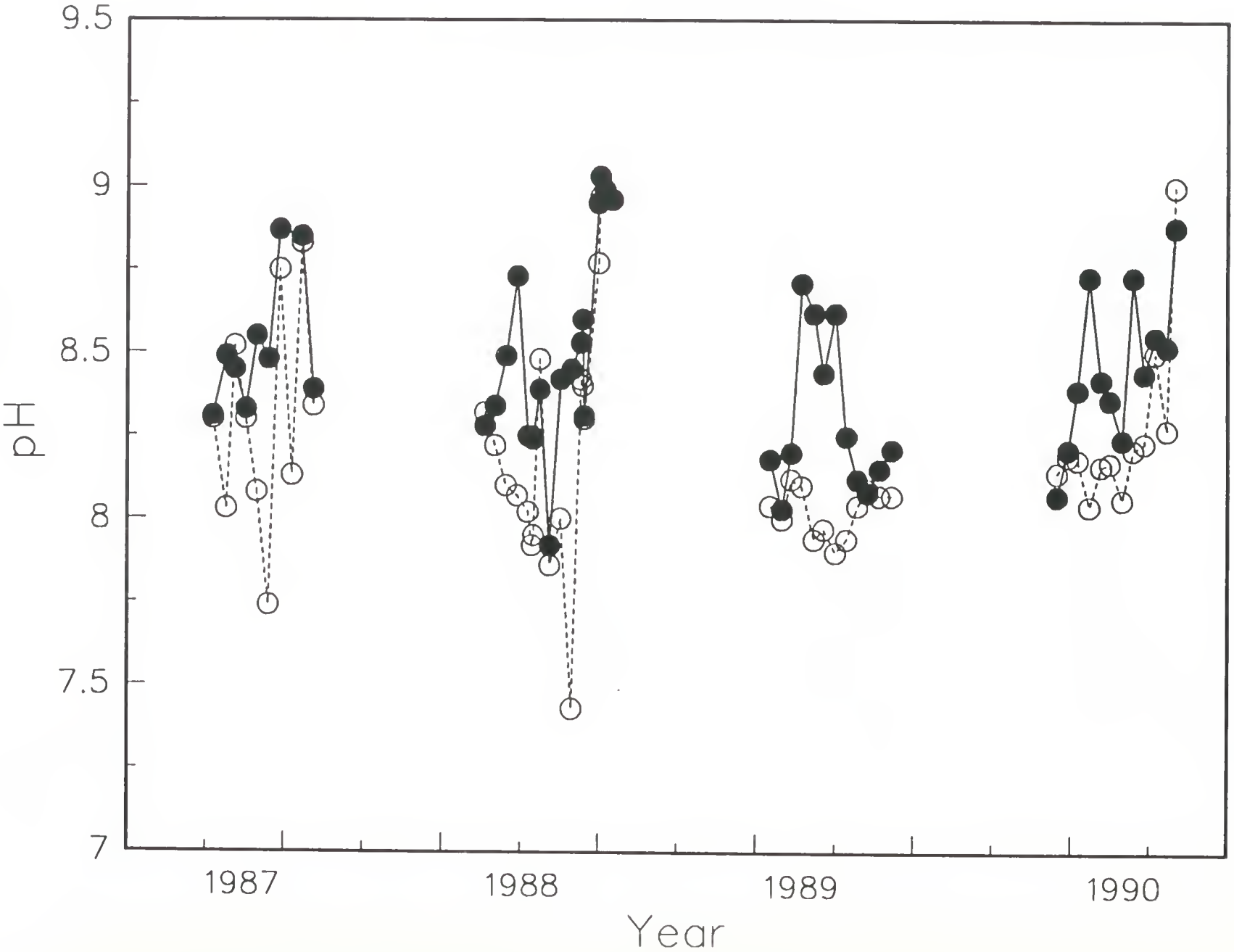


Fig. 19

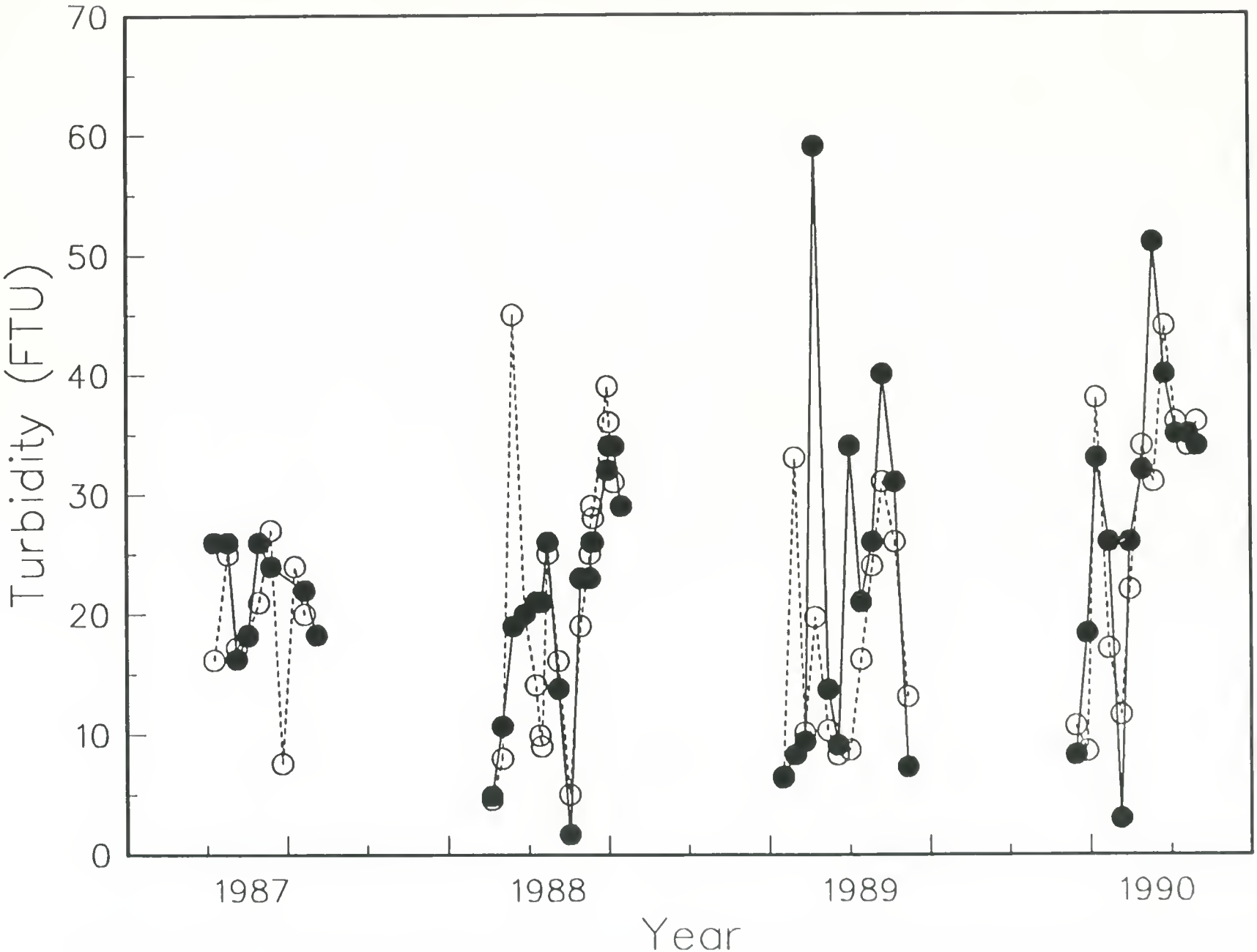


Fig. 20

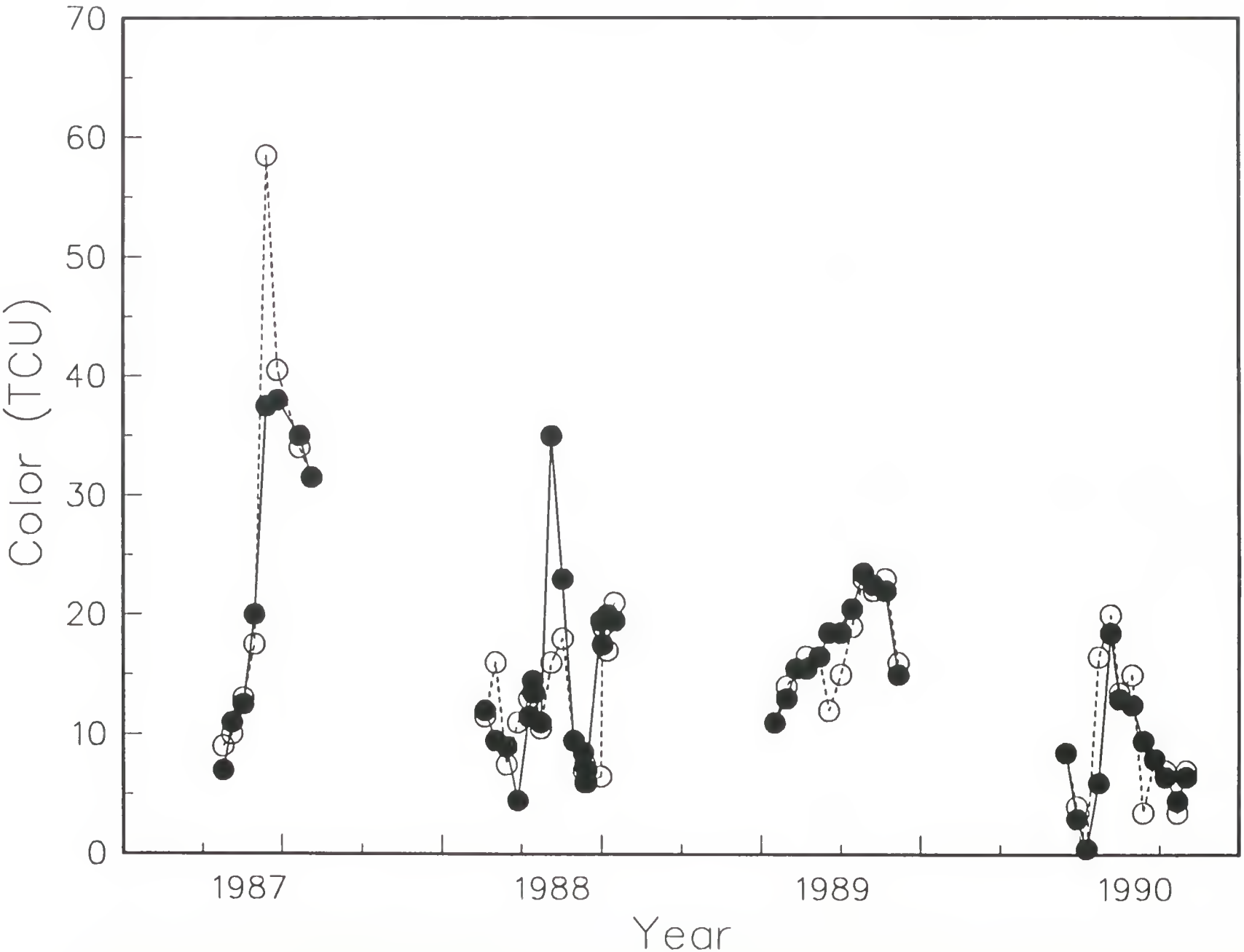


Fig. 21

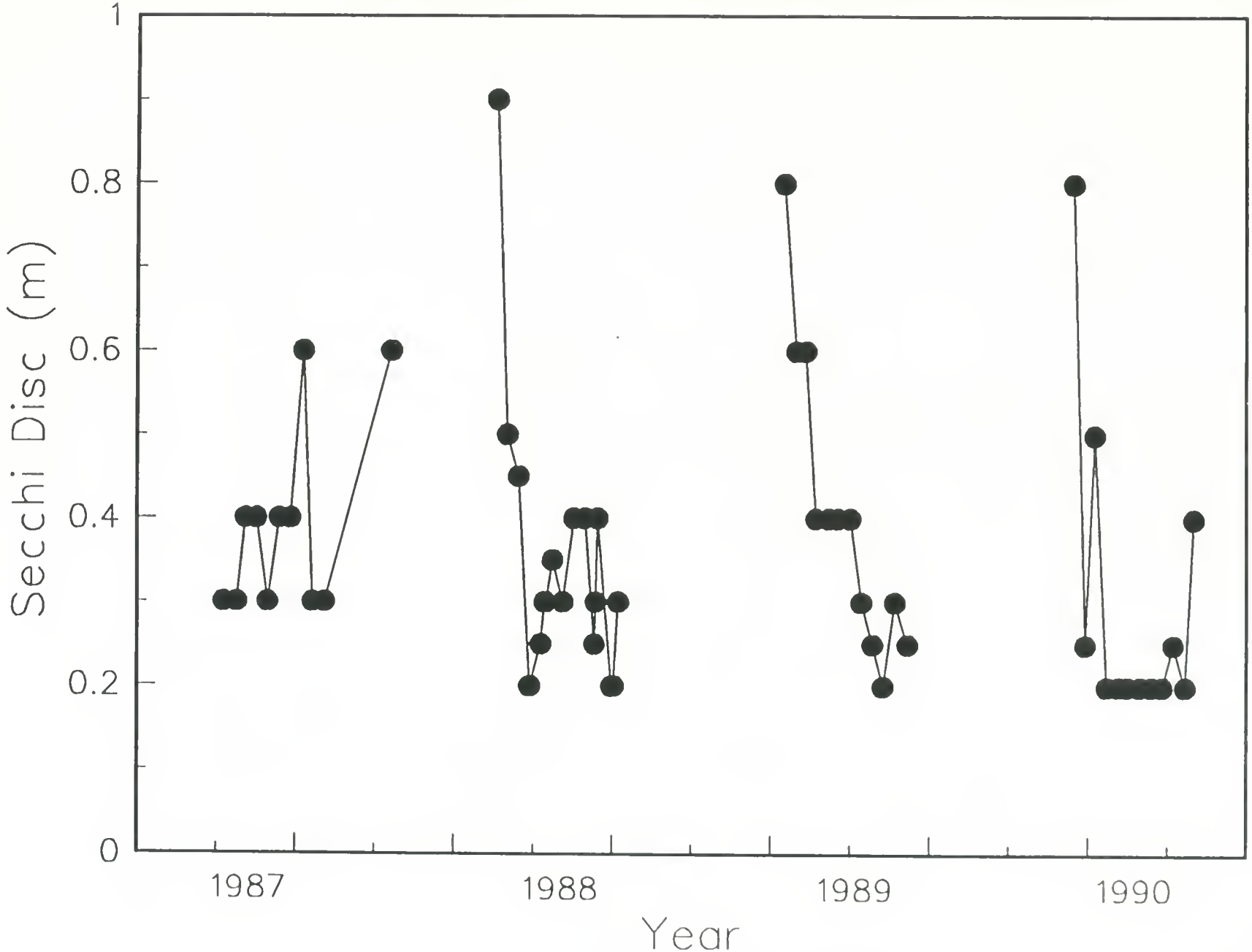


Fig. 22

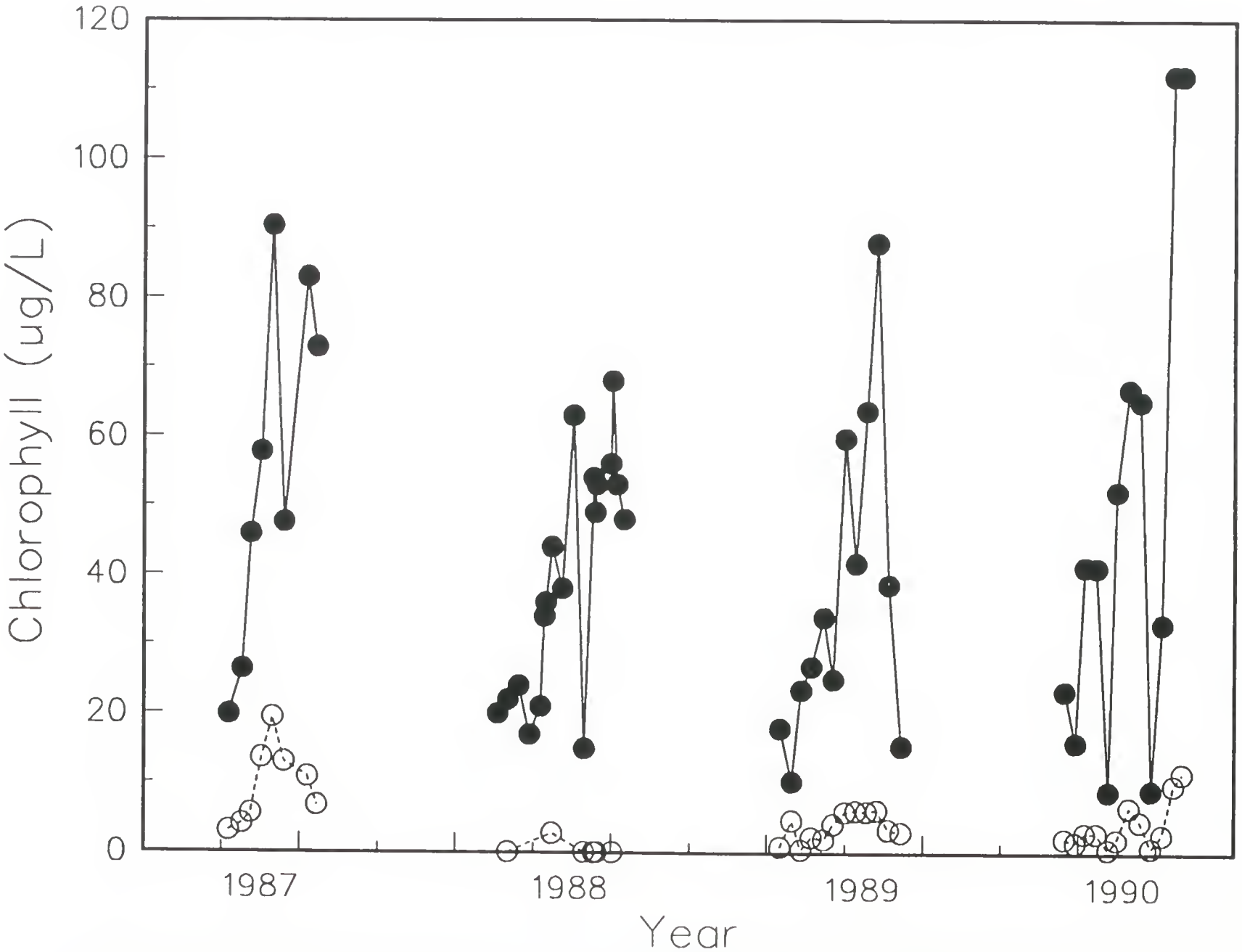


Fig. 23

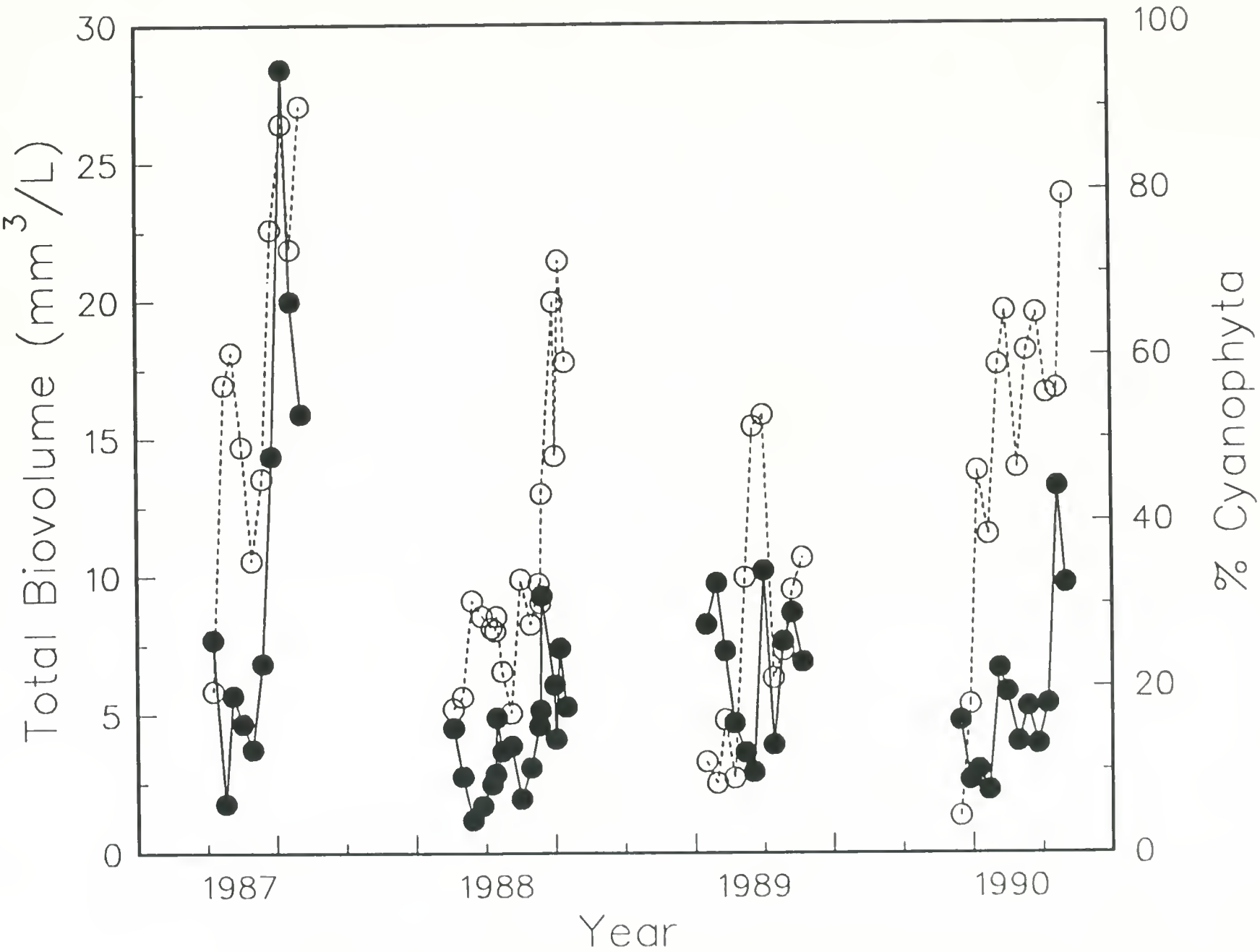

Total Biovolume (mm^3/L)
% Cyanophyta
Year
1987
1988
1989
1990
0
5
10
15
20
25
30
0
20
40
60
80
100

Fig. 24

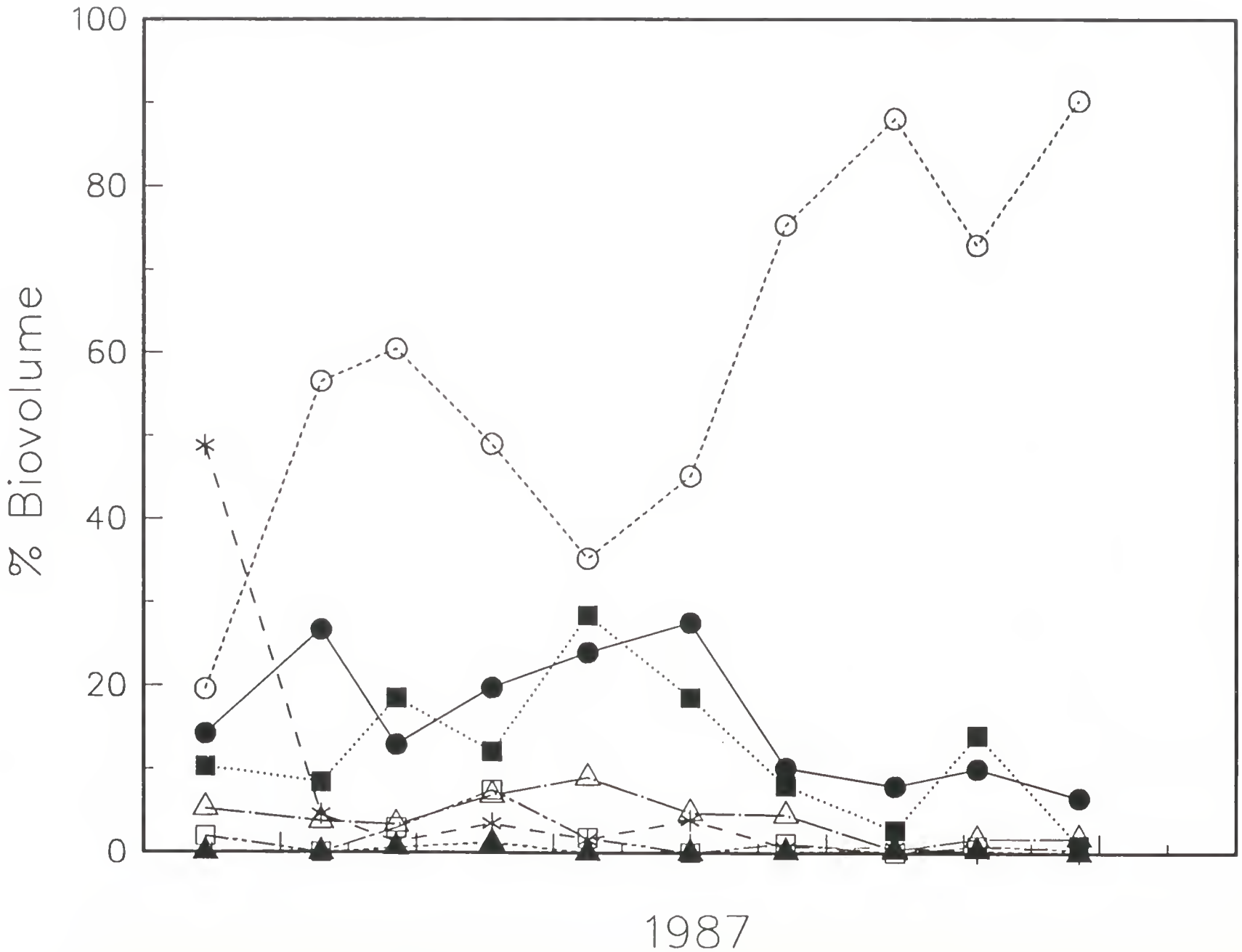


Fig. 25

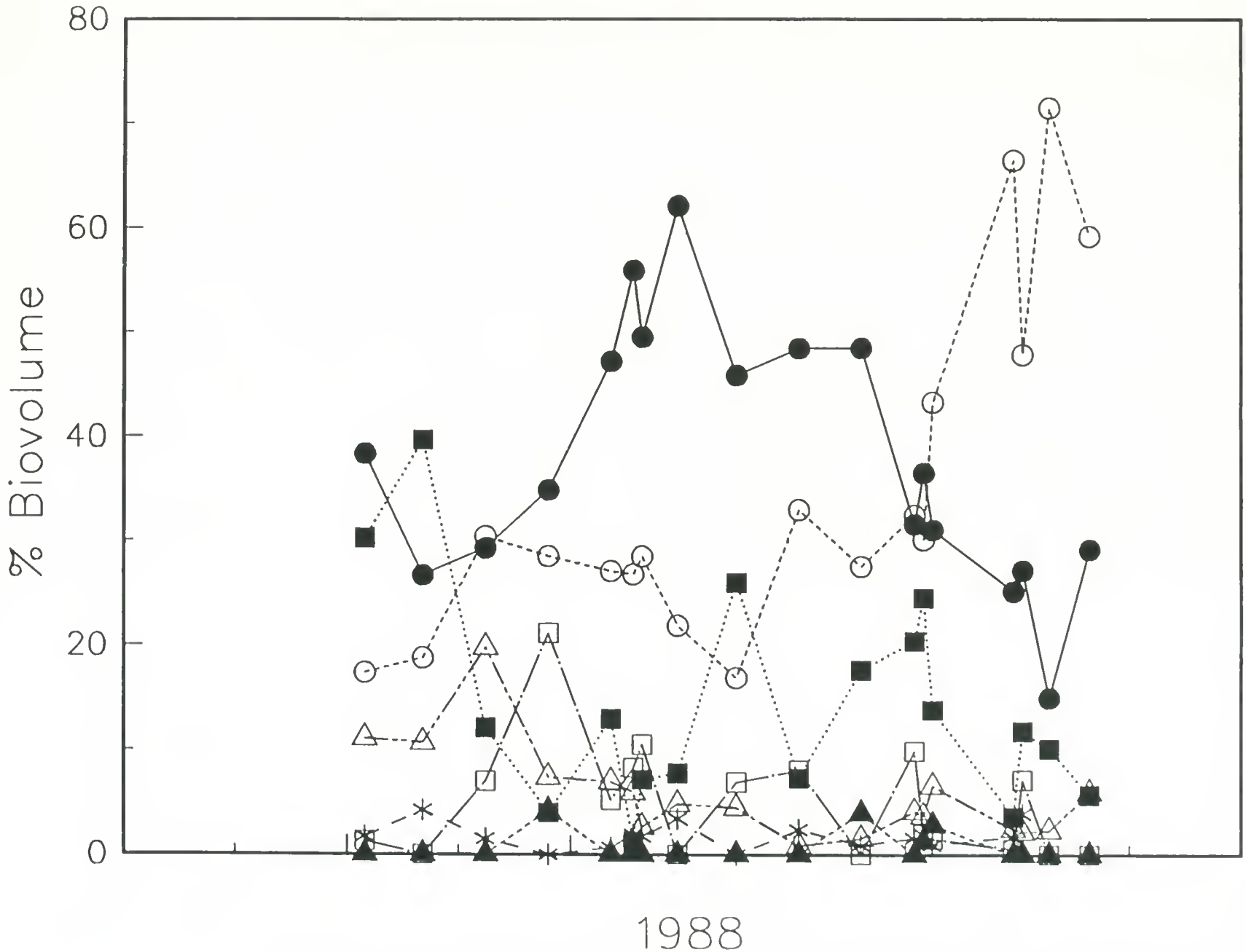


Fig. 26

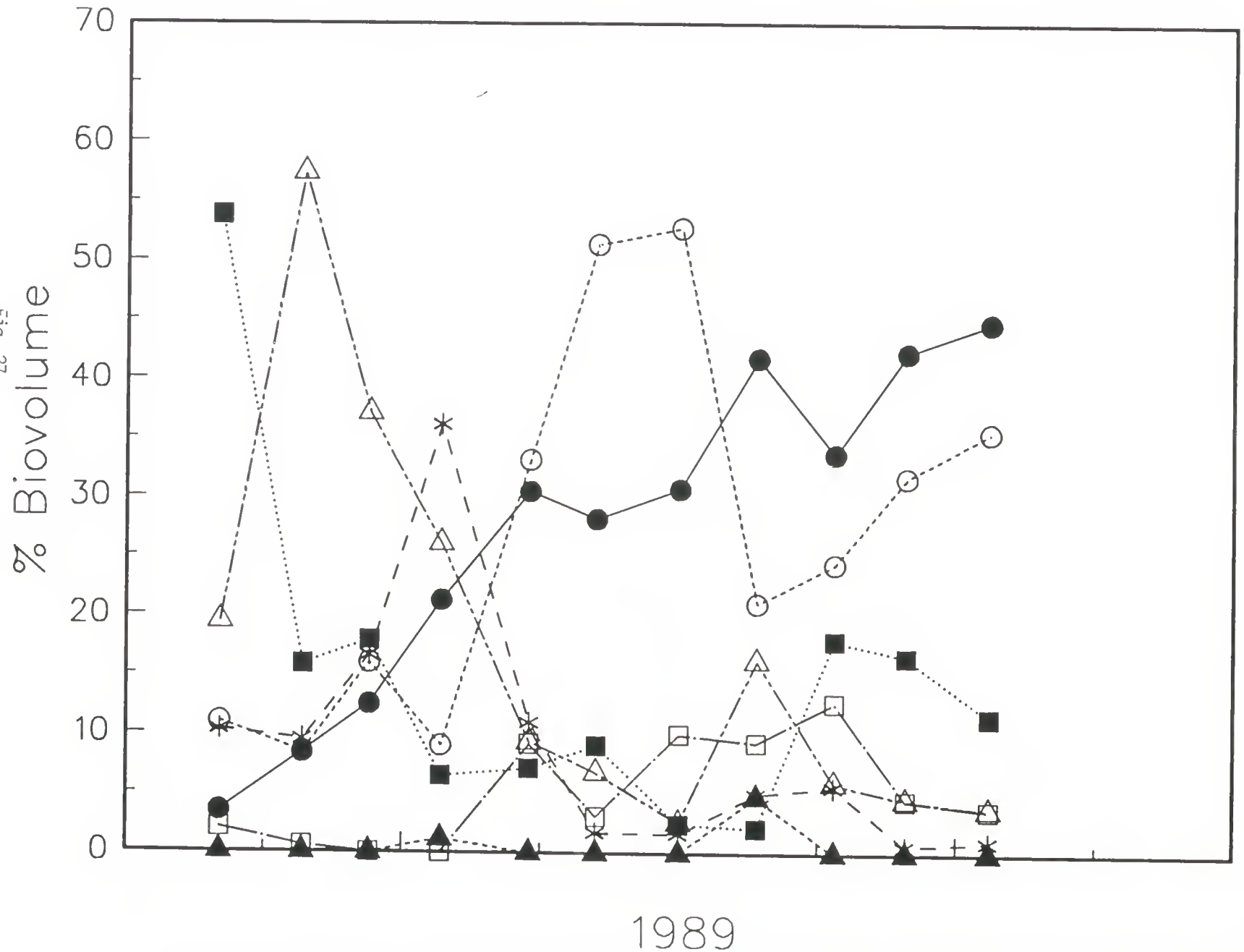


Fig. 27

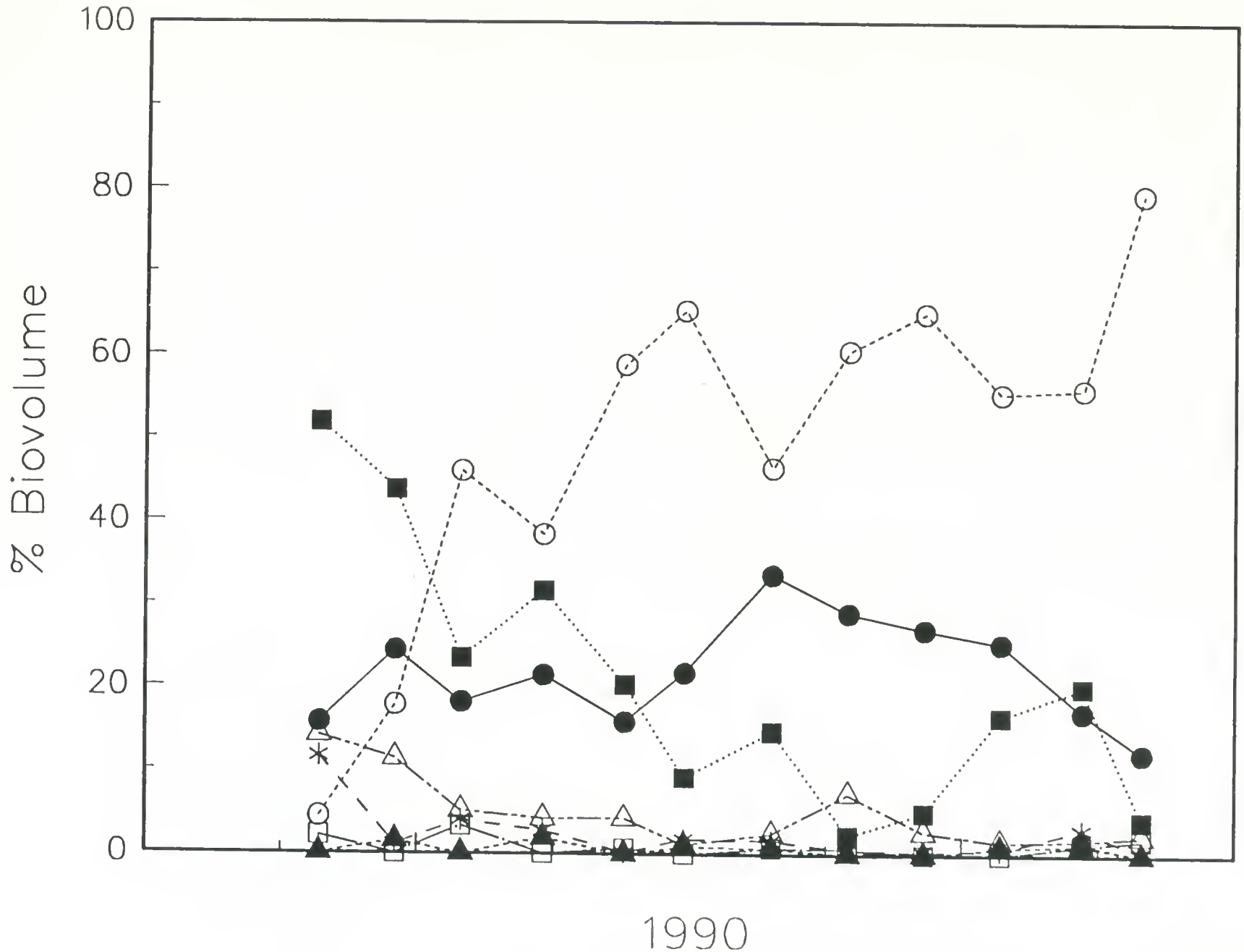
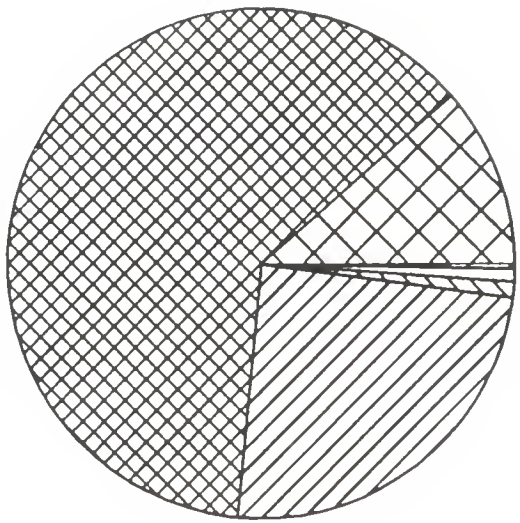
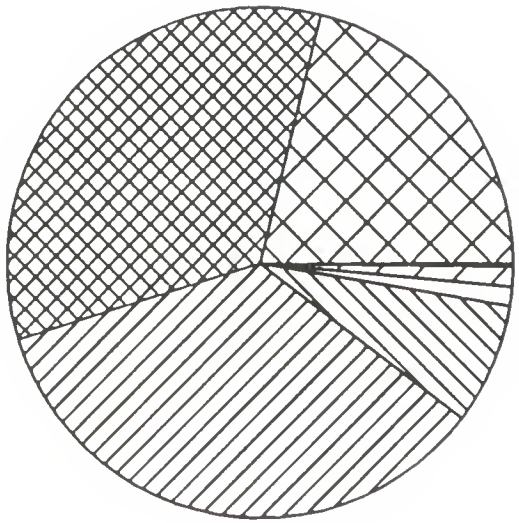


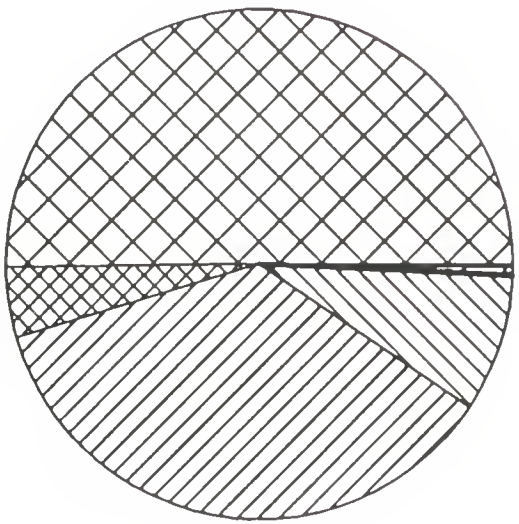
Fig. 28



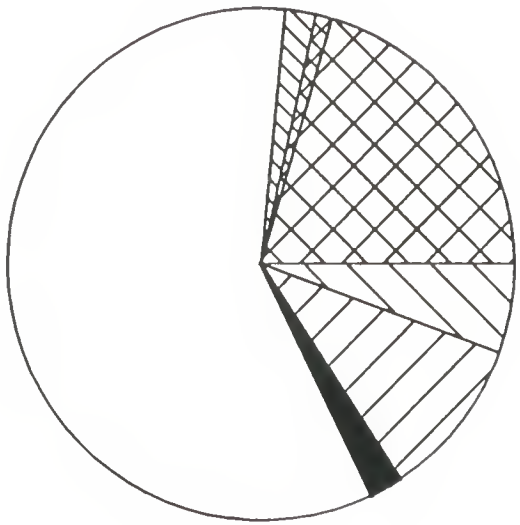
1987



1988



1989



1990

Fig. 29

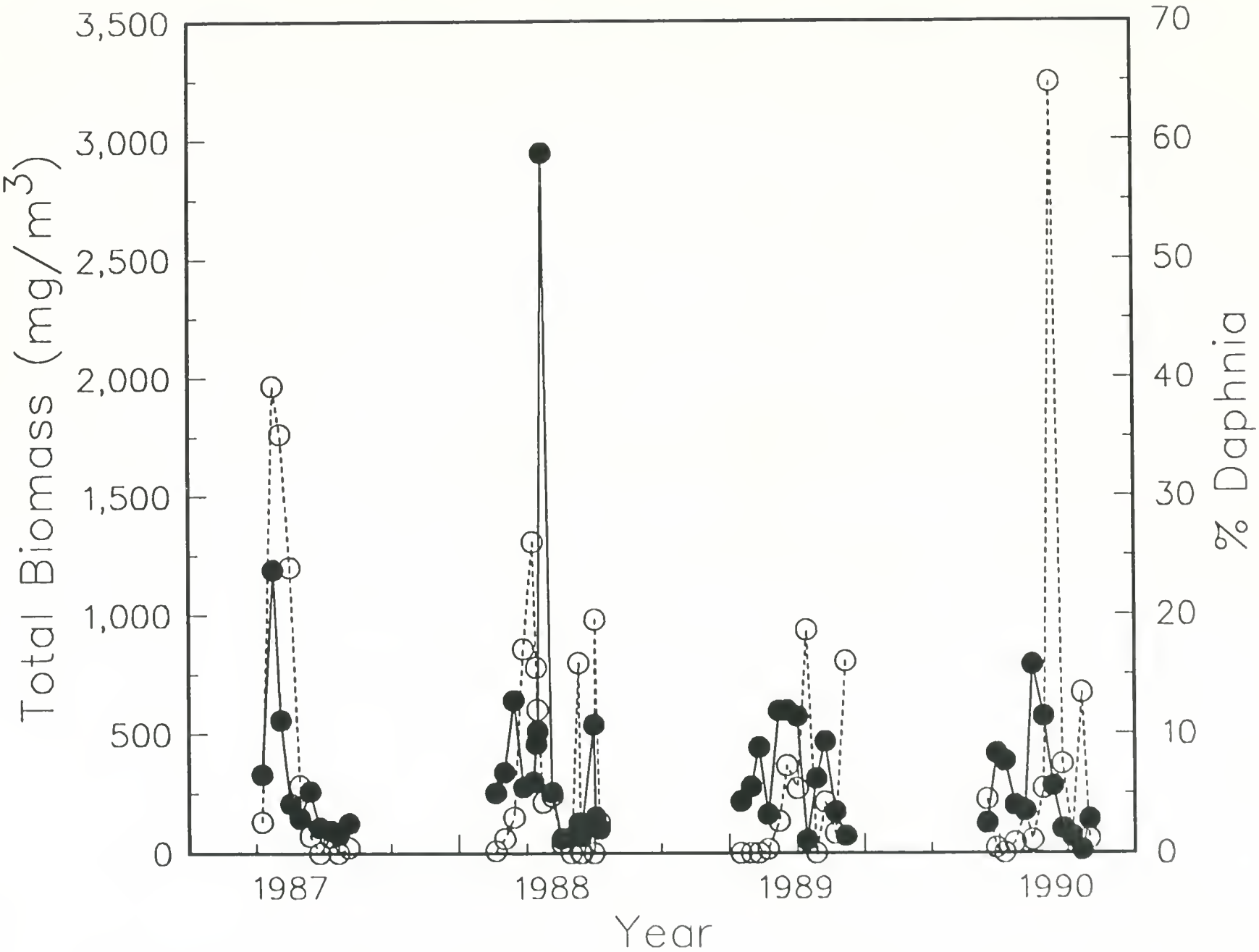

3,500
3,000
2,500
2,000
1,500
1,000
500
0
Total Biomass (mg/m3)
70
60
50
40
30
20
10
0
% Daphnia
1987
1988
1989
1990
Year

Fig. 30

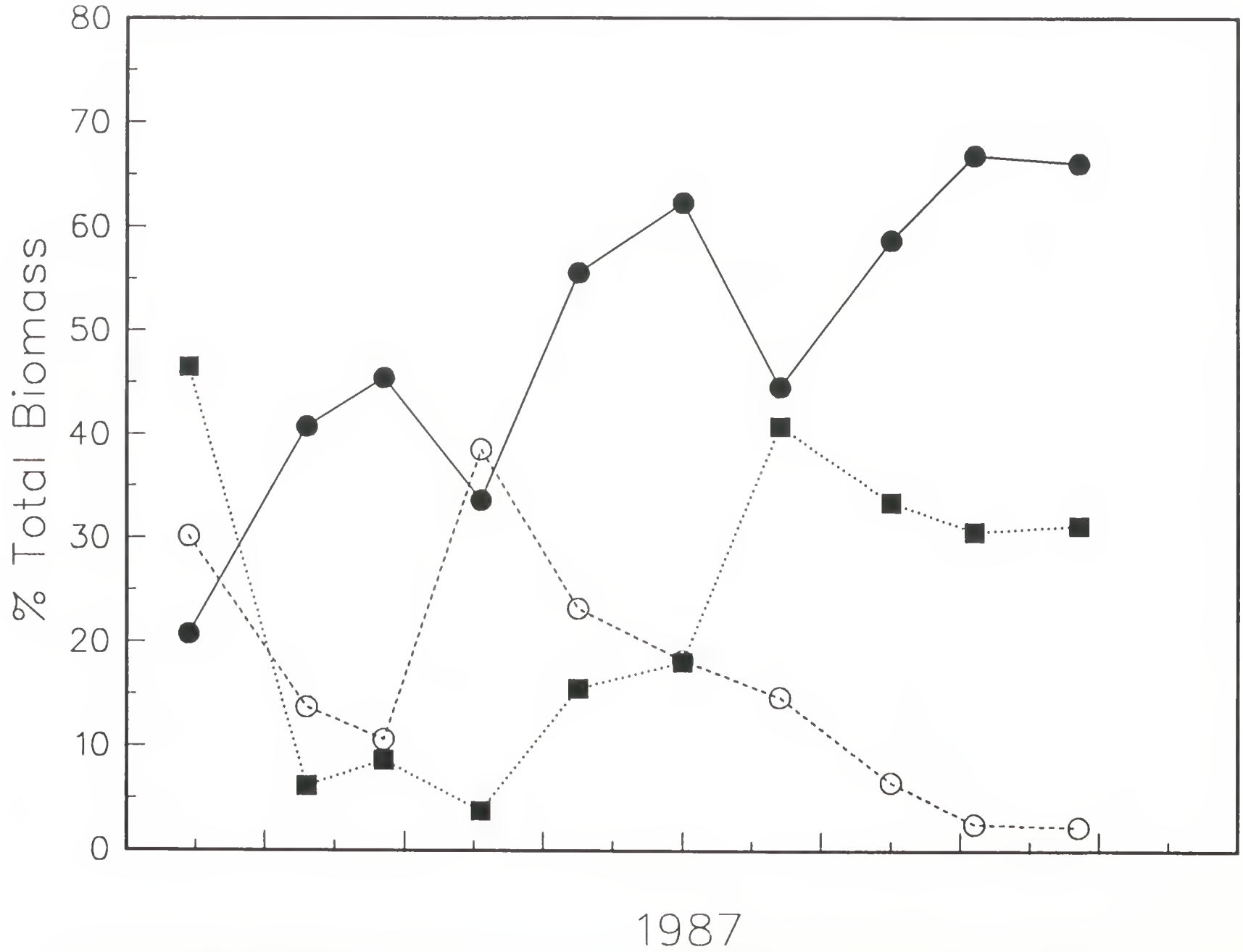


Fig. 31

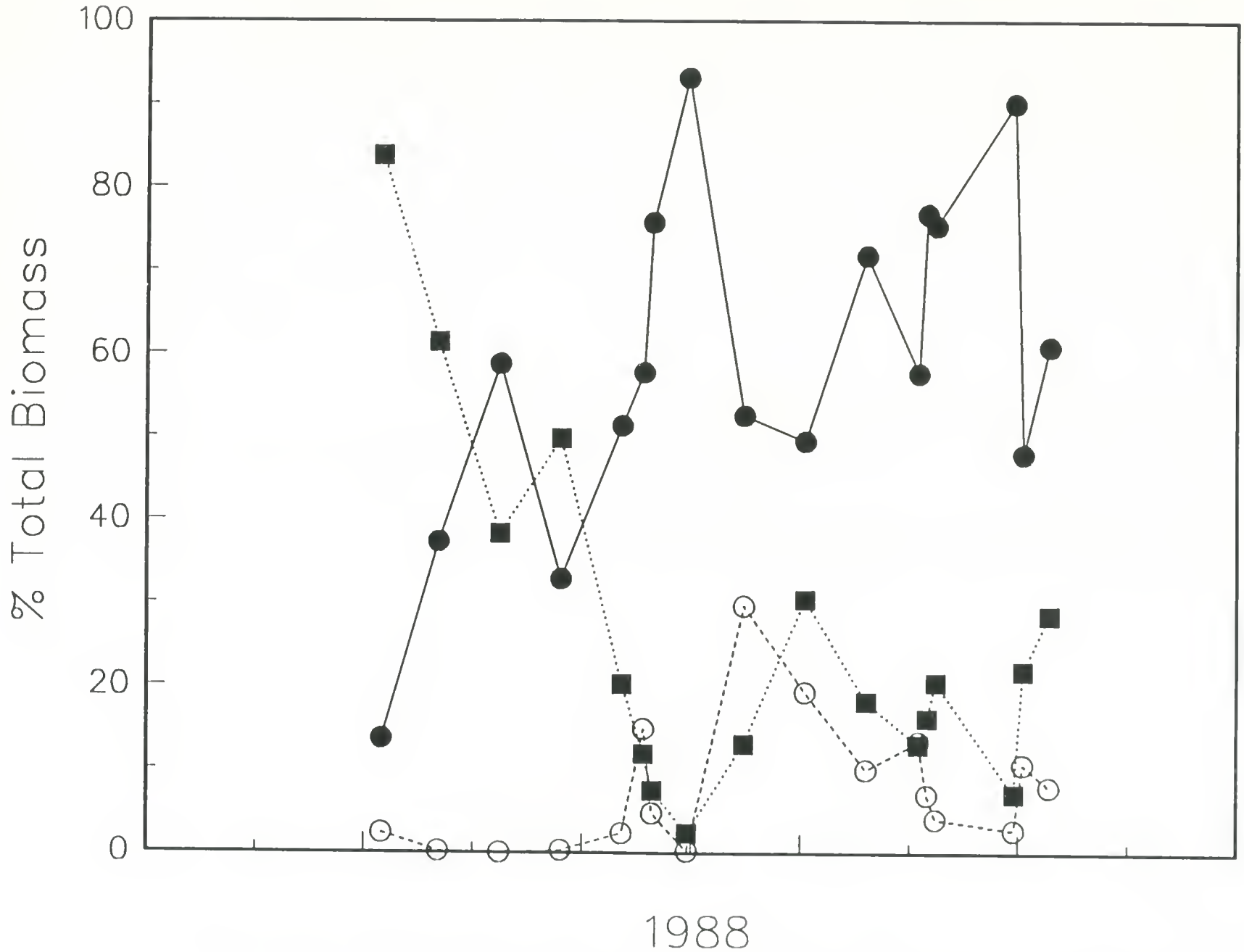


Fig. 32

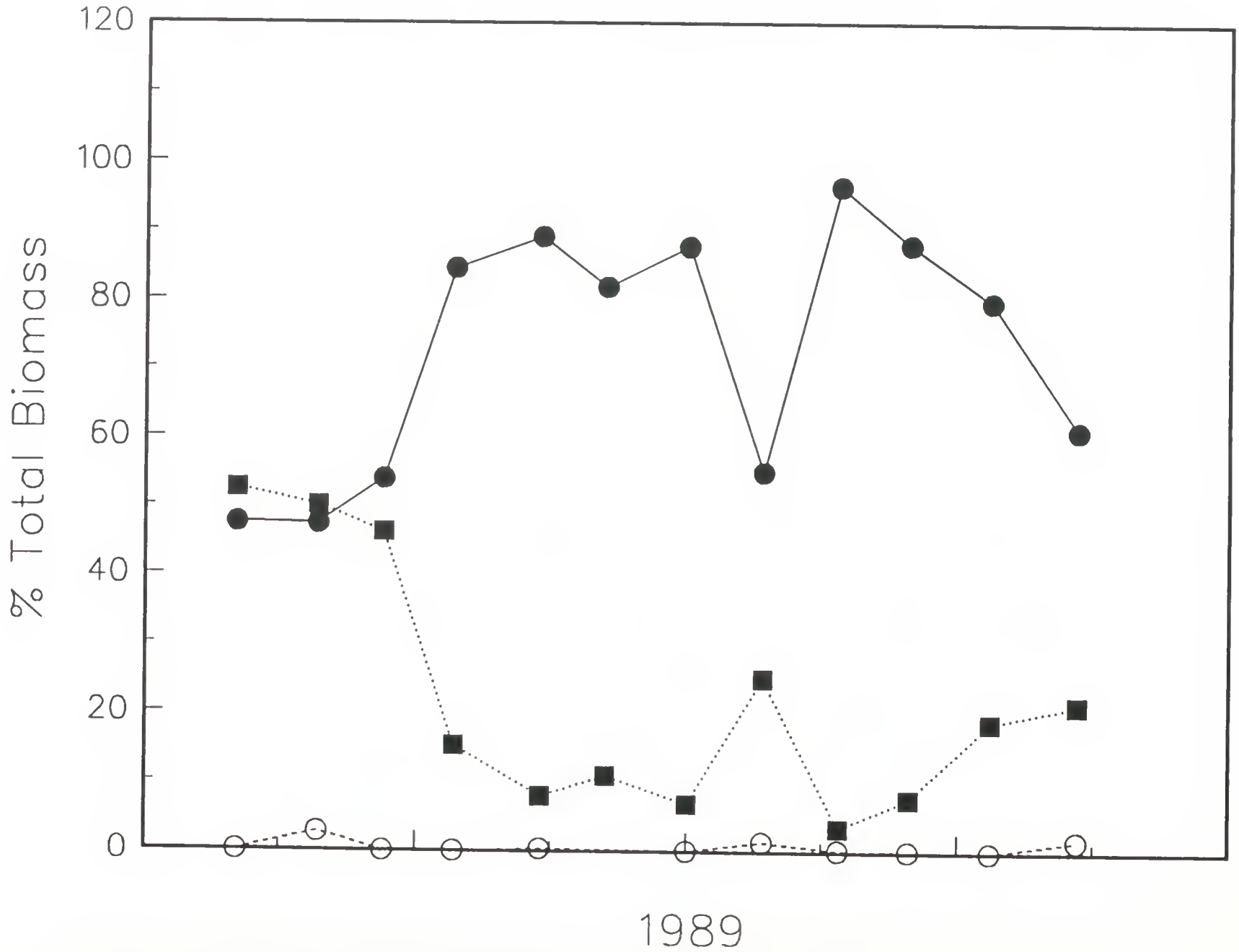


Fig. 33

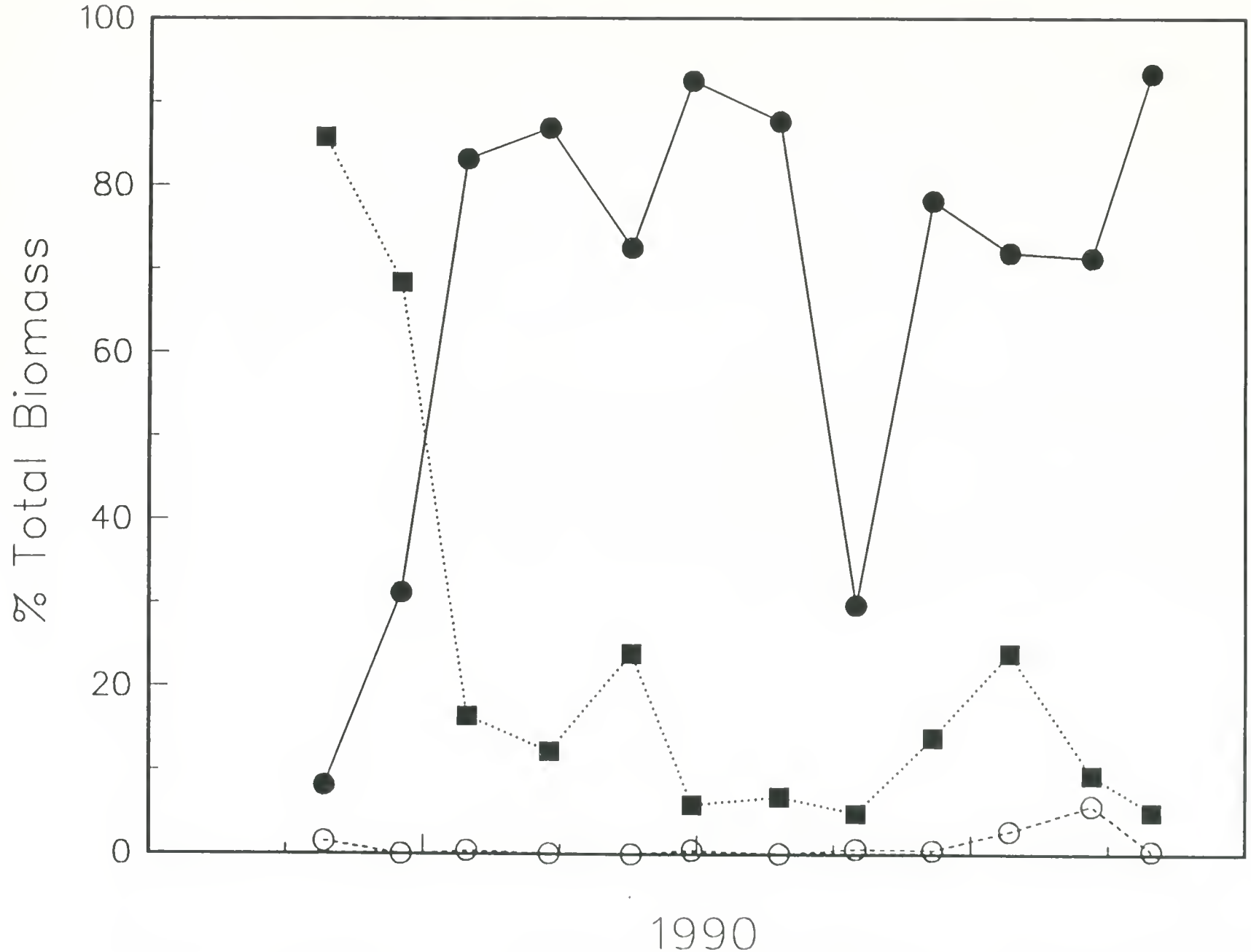


Fig. 34

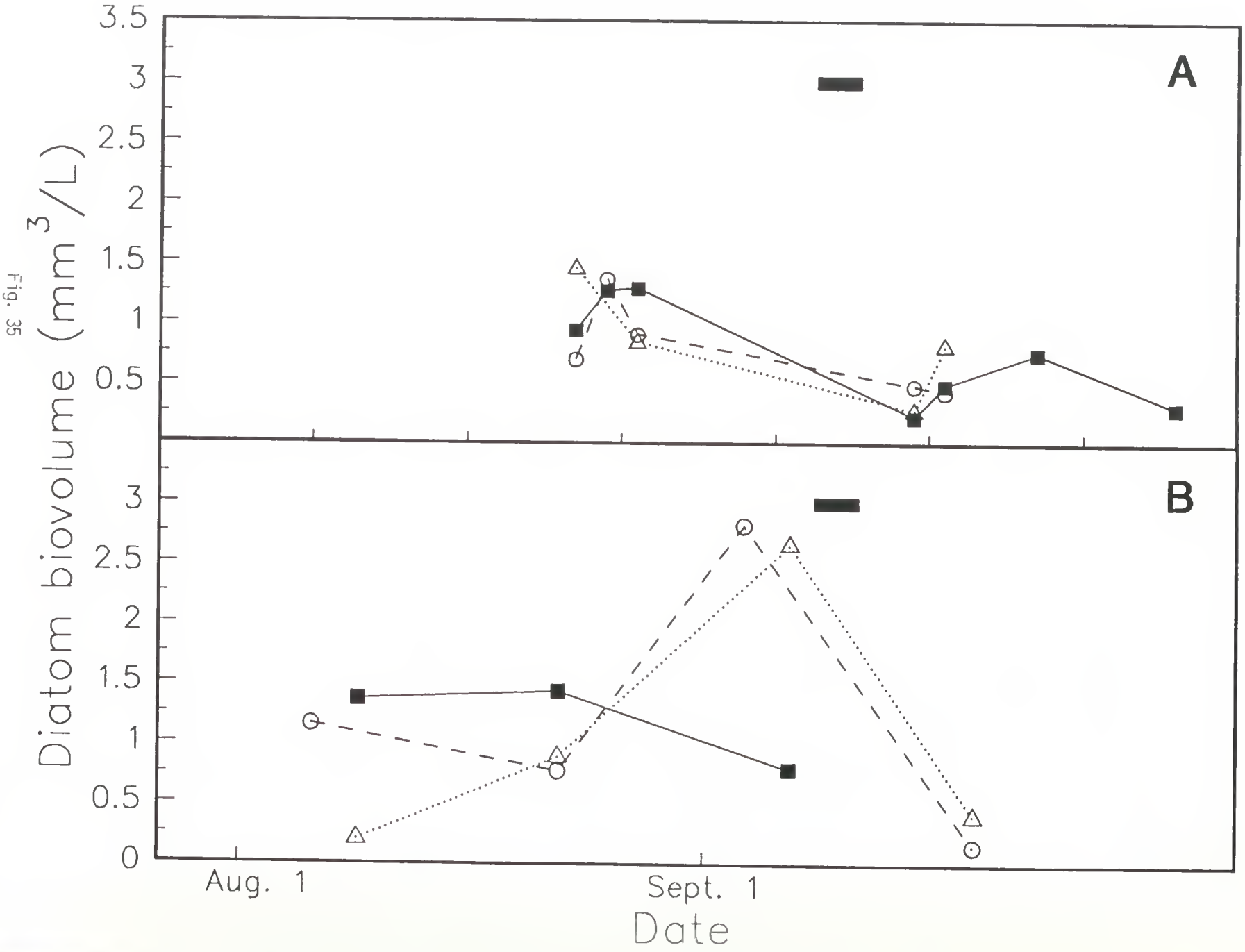


Fig. 35

Appendix I. Metal and nutrient concentrations in sediment samples collected on December 10, 1987. Means ± S.E.

	Site A	Site B	Site C	Site D
Iron (ug/g dry as Fe)	5230 ± 108	6230 ± 363	8870 ± 726	6670 ± 108
Zinc (ug/g dry as Zn)	97.3 ± 2.7	113 ± 12 †	190 ± 19 †	147 ± 8 †
Lead (ug/g dry as Pb)	64.7 ± 7.6 †	59.3 ± 5.1 †	117 ± 20 †	90.0 ± 6.3 †
Copper (ug/g dry as Cu)	9.8 ± 0.2	11.7 ± 1.1	20.0 ± 1.9	16.0 ± 1.2
Chromium (ug/g dry as Cr)	9.1 ± 0.2	7.3 ± 0.3	12.0 ± 2.1	8.9 ± 0.3
Nickel (ug/g dry as Ni)	3.9 ± 0.3	4.7 ± 0.4	8.1 ± 1.0	6.5 ± 0.4
Arsenic (ug/g dry as As)	4.3 ± 0.4	5.3 ± 0.6	5.7 ± 1.1	6.1 ± 0.7
Cobalt (ug/g dry as Co)	4.1 ± 0.1	4.3 ± 0.2	6.3 ± 0.7	4.8 ± 0.1
Selenium (ug/g dry as Se)	0.95 ± 0.13	1.6 ± 0.1	2.3 ± 0.3 ‡	1.9 ± 0.2
Molybdenum (ug/g dry as Mo)	N.D.	1.5 ± 0.1	1.3 ± 0.1	1.4 ± 0.2
Cadmium (ug/g dry as Cd)	0.82 ± 0.03	1.1 ± 0.1 †	1.6 ± 0.2 †	1.33 ± 0.04 †
Mercury (ug/g dry as Hg)	0.05 ± 0	0.10 ± 0.03	0.15 ± 0.03	0.12 ± 0.02
loss on ignition (mg/g dry)	313 ± 4 †	510 ± 26 †	567 ± 48 †	427 ± 53 †
Kjeldahl nitrogen (mg/g dry as N)	11.9 ± 0.2 †	23.7 ± 3.0 †	30.2 ± 2.1 †	22.2 ± 4.3 †
Phosphorus (mg/g dry as P)	0.43 ± 0.02	0.45 ± 0.18	1.3 ± 0.2 †	1.0 ± 0.2

† value exceeds open water disposal guidelines for dredged materials (M.O.E. 1991a)

‡ value exceeds agricultural/residential/parkland disposal guidelines for dredged materials (M.O.E. 1991a)

Appendix II.

PUSLINCH LAKE MACROPHYTE SURVEY - 1987

Prepared for

Ontario Ministry of the Environment

Limnos Limited

Jeff Graham, B.Sc. (Eng.)
Jeff Warren, B.Sc.

January, 1988

EXECUTIVE SUMMARY

Two surveys of aquatic plant growth in Puslinch Lake, Ontario, were conducted during 1987. The early summer survey was completed between June 22 and June 24, 1987, and the late summer survey between September 1 and September 4, 1987. Approximately 54 hectares, or 33% of the lake area supported macrophyte growth during the early summer survey. During the late summer survey, approximately 31 hectares, or 19% of the lake area supported plant growth. Growth of macrophytes was largely restricted to waters 1 m or less. Predominant species included Potamogeton amplifolius, Myriophyllum spicatum, and Chara. Remnant growth of Potamogeton crispus was observed during the early summer survey. No growth of Potamogeton crispus was observed during the late summer survey.

Total macrophyte biomass was estimated to be 151 t and 34.2 t (wet mass) at the time of the early summer and late summer surveys, respectively. Total phosphorus contained in the macrophyte biomass (excluding Chara) was estimated to be 21.6 kg and 8.0 kg for the early summer and late summer survey periods, respectively. Similarly, total, contained nitrogen resources was estimated to be 249 kg and 71 kg for the early summer and late summer survey periods, respectively. Exclusive of Chara, biomass on a unit area basis was estimated to be 280.2 g/m^2 and 110.4 g/m^2 (wet mass) for the early summer and late summer surveys, respectively.

Density of Potamogeton crispus turions in lake sediments was relatively low (less than 250 per m^2), indicating that early spring growth of Potamogeton crispus is minimal. Turion distribution patterns indicated that growth of Potamogeton crispus is largely restricted to depths less than 1.5 m. Poor water clarity (Secchi depth between 0.3 and 0.4 m) probably limits the present macrophyte distribution to relatively shallow areas.

It is concluded that the diversity of aquatic plant species is low, and during the surveys the growth of macrophytes was discontinuous in available habitat. An assessment of plant nutrients contained in the total macrophyte biomass indicated that macrophytes do not utilize a major quantity of the available plant nutrient resources. P. crispus may be more abundant during the spring resulting in lake use interference and a spring survey is recommended to determine its role in the dynamics of aquatic macrophyte populations in Puslinch Lake.

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PUSLINCH LAKE MACROPHYTE SURVEY - 1987

INTRODUCTION

Puslinch Lake is located in the southwest portion of Puslinch township in Wellington County, Ontario. The average depth of the lake is approximately 2 m, and has a maximum depth of about 4 m. The surface area of the lake is approximately 160 hectares. Most of the shoreline is occupied by seasonal and permanent residential development. A marina and a trailer park and beach development have also been established. A 120 hectare conservation area owned by the Grand River Conservation Authority is located at the south west corner of the lake.

A 1980 survey of cottage association members indicated that water pollution and aquatic plant growth were perceived to be the most important problems affecting lake use and enjoyment (Whitehead, 1980). To document aquatic plant growth and to investigate possible effects of plant growth on water quality, a survey of aquatic plant growth in Puslinch Lake was completed during 1987. Of particular interest was determining the distribution and biomass of *Potamogeton crispus* in the lake. In Southern Ontario lakes where present, this species normally develops in early spring, and senesces by the end of June. In lakes with heavy growth of *P. crispus*, there is the potential for significant release of phosphorus from decaying plants to the water column.

OBJECTIVES

The objectives of the survey were as follows:

1) Determine aquatic plant species composition and distribution in Puslinch Lake during early and late summer.

2) Determine aquatic plant biomass and nutrient content of the standing macrophyte crop, and changes in biomass and nutrient content during the summer period.

METHODS

Distribution and Species Composition

A small boat with a 9.9 hp motor was used for the aquatic plant survey. The boat was equipped with a Raytheon Fathometer Chart recorder that recorded water depth, aquatic plant abundance, and height of plant growth in the water column on permanent, paper tracings. The distribution of aquatic plants was determined by running randomly selected transects through all lake areas. Transects normally began and ended at shorelines, islands, or points.

Plants growing to the water surface were identified from the boat. Anchor drags recovered submerged, non - visible plants for identification that were graphed by the chart recorder. Biomass collections also determined species composition at sampling locations. Specimens of all species recovered during the survey were identified by a staff biologist.

During the late summer survey, sediment samples were collected with an Ekman dredge. Potamogeton crispus turions recovered from the sediment samples were counted, and the water depth at the sampling site recorded. Previous studies of P. crispus in Rice Lake revealed that sediment turion density reflects the biomass of P. crispus that develops at the sampling point (Limnos Limited, Rice Lake Study - Interim Report 1987). The number of turions recovered would thus provide an indication of distribution and biomass of early spring P. crispus growth in Puslinch Lake.

Biomass and Nutrient Content

Biomass samples were collected from different lake areas that had previously been noted to support plant growth. Biomass samples were collected from the same locations during the early summer and late summer surveys. At each sampling location, a diver collected all plant material above the sediment from within a randomly cast, $0.25m^2$ quadrant. Three quadrants from each sample point were combined to form the biomass sample.

Following collection, the species composition of the samples was described on a percentage basis. The plant samples were placed in a household salad spinner, and spun to remove surficial water. Use of a salad spinner for this purpose has been described elsewhere by the authors (Limnos Limited, Dichotomosiphon tuberosus in Lake Simcoe 1987). The wet mass of samples were subsequently determined with a triple beam balance, and the volume of the sample measured in a graduated cylinder by water displacement. During the fall survey, biomass samples were also dried and the dry mass determined. Samples of predominant species were frozen and submitted for analysis of organic content, and nitrogen and phosphorus content.

RESULTS

Distribution and Species Composition

Early Summer Survey

Seventeen survey transects were run between June 22 and June 24, 1987. The locations of these transects (transects 1 to 17) are shown on Figure 1. Table 1 in the appendix describes macrophyte presence or absence along each survey transect, and what species were observed or recovered. The maximum depth recorded along each transect is also given in Table 1.

Figure 2 indicates areas of the lake supporting macrophyte growth at the time of the early summer survey. Plant growth occurred along the eastern and western shorelines, the bays along the south shore, and north west of Big Island. Appoximately 54 hectares or 33% of the lake area supported macrophyte growth at this time. Growth of macrophytes was mainly restricted to water depths of 1 m or less. Figure 3 presents a portion of the chart recording from transect 9 (early summer survey) showing aquatic plant growth, height of growth in the water column, the sediment surface and the water surface. To determine areal coverage of macrophyte growth, the fathometer paper tracings were reviewed in conjunction with the hydrographic sheet, and coverage interpolated onto the hydrographic sheet. The areal coverage was then measured by planimetery.

Species diversity was low; only four species were commonly observed during the early summer survey period. These species were Potamogeton amplifolius, Chara, Myriophyllum spicatum, and Potamogeton crispus. Only remnant growth of mature P. crispus remained at this time, however.

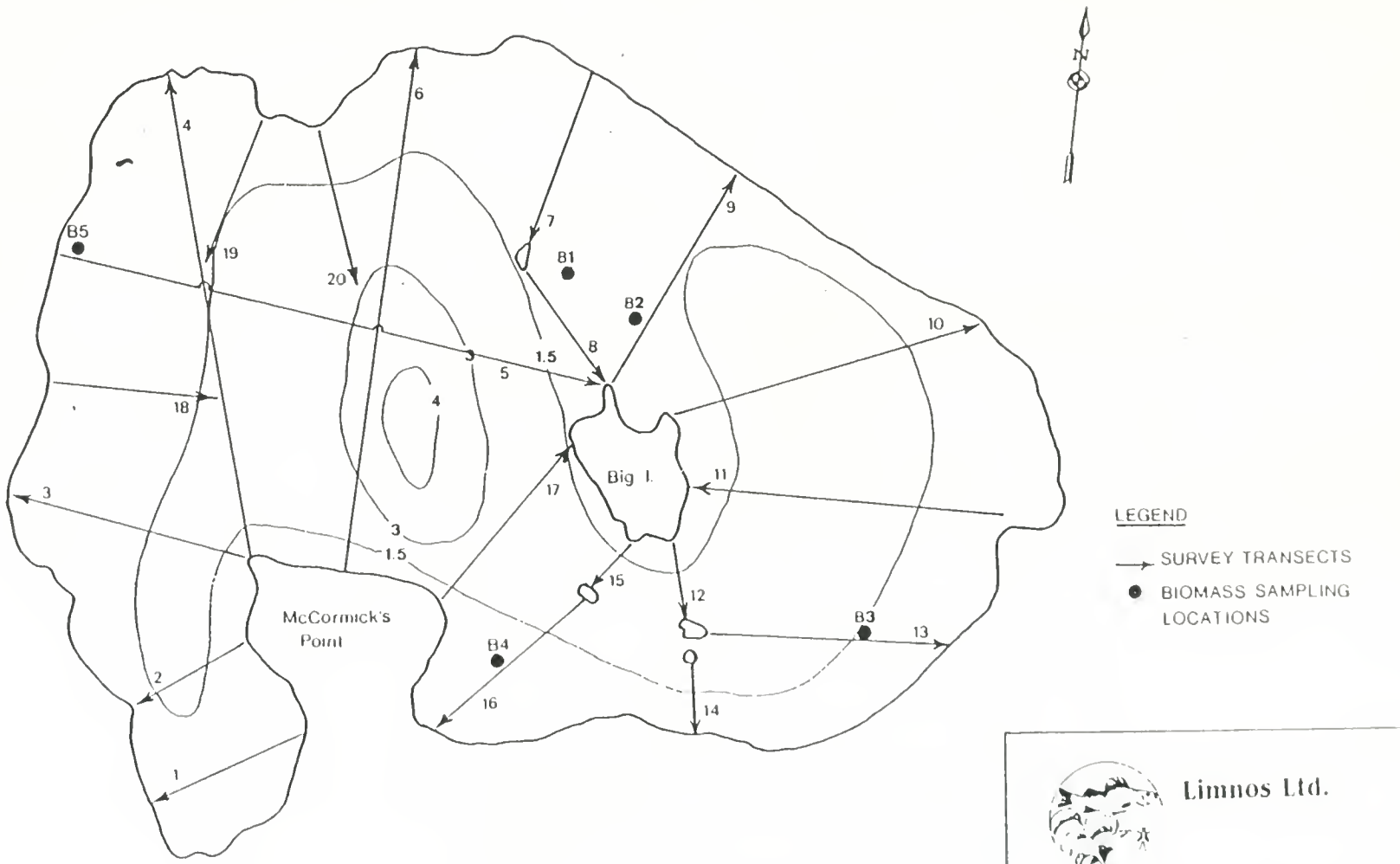


Figure 1. Survey Transects and Biomass Sampling Locations

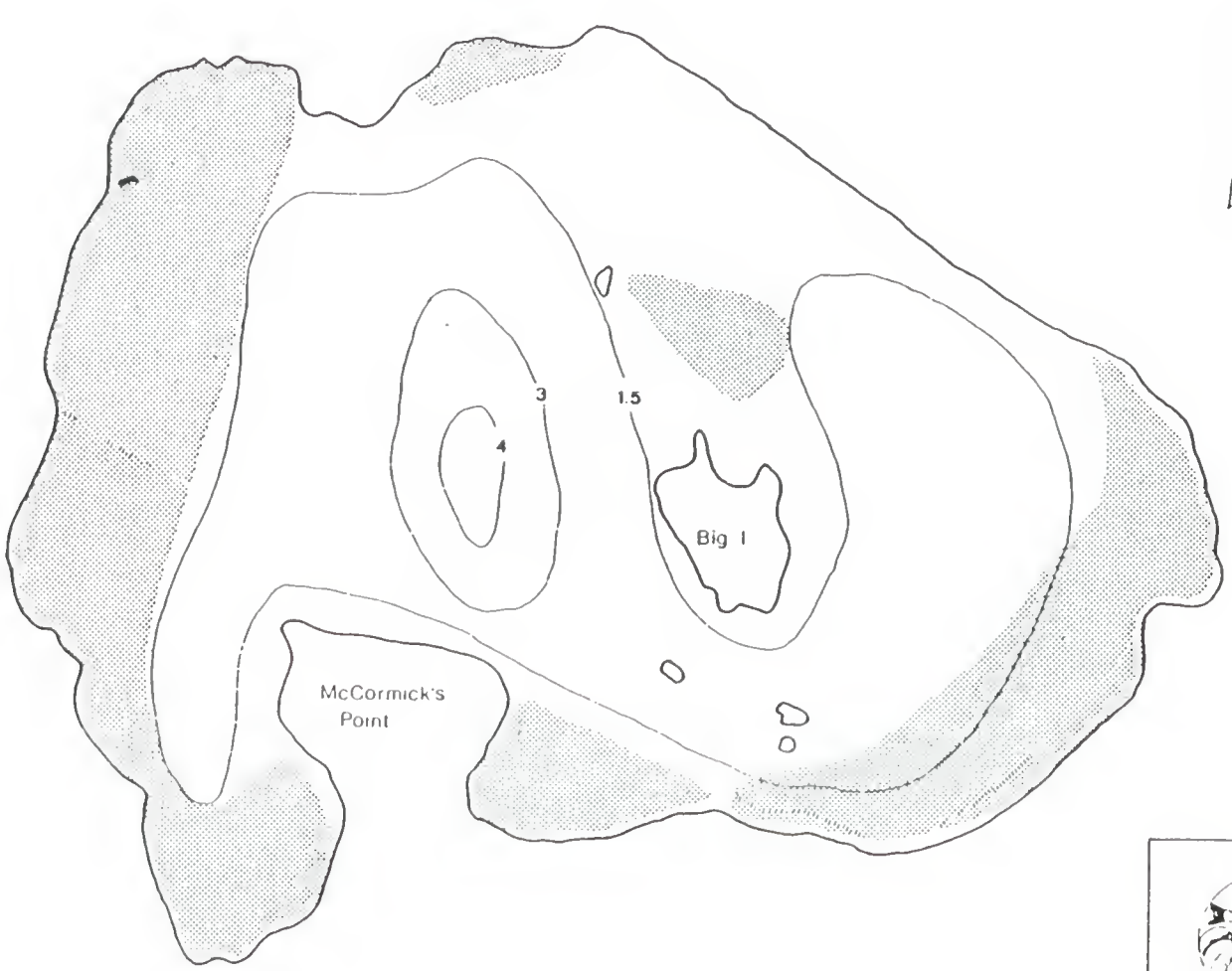
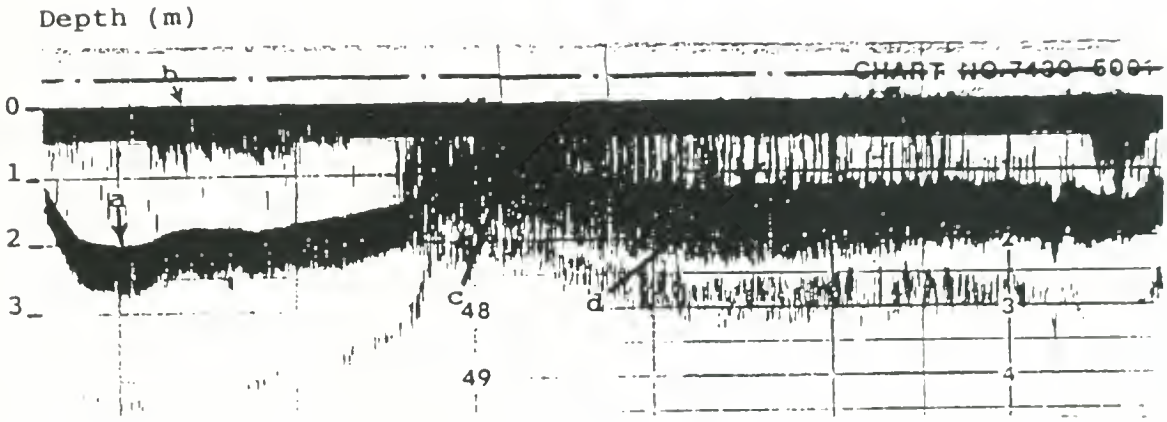


Figure 2. Distribution of Macrophyte Growth during Early Summer - 1987



Sediment Surface (a)

Surface Reflection (b)

Continuous Macrophyte Growth (c)

Discontinuous Macrophyte Growth (d)

Figure 3. Segment of Echo Tracing of Transect 9 (Early Summer Survey) showing Macrophyte Growth, Water Depth, Surface, and Sediment Surface.

Senescence of P. crispus was indicated by slumping and unhealthy plants, and by decomposing plants recovered from the bottom by anchor drags. P. crispus plants were recovered to 1.5 m, indicating that P. crispus occupies deeper waters than other macrophytes.

Late Summer Survey

The late summer survey was conducted between September 1 and September 4, 1987. The transects run during the early summer survey were repeated during the late summer survey. Three additional transects were run during the early fall survey (transects 18, 19 and 20 shown in Figure 1). Table 2 in the appendix describes macrophyte status for each transect, as well as the maximum depth recorded along each transect.

Figure 4 shows the lake area supporting macrophyte growth during early September. Approximately 31 hectares or 19% of the lake area supported macrophyte growth at this time. While still present, growth of P. amplifolius and M. spicatum was less widespread and less dense than observed during the early summer survey. No growth of P. crispus was observed. Density and distribution of Chara had not appreciably changed during the summer.

Twenty seven sediment samples were collected using an Ekman dredge from water depths between 0.75 and 1.75 m. Small numbers (less than 250 per m^2) of P. crispus turions were recovered from the sediment samples, and few turions were recovered from sediment samples collected in waters deeper than 1.5 m. Based on previous work by the authors, these results would indicate that a relatively low biomass (i.e. less than 500 g/m^2 wet mass) of P. crispus develops in the early spring, and that growth is largely restricted to water depths less than 1.5 m.

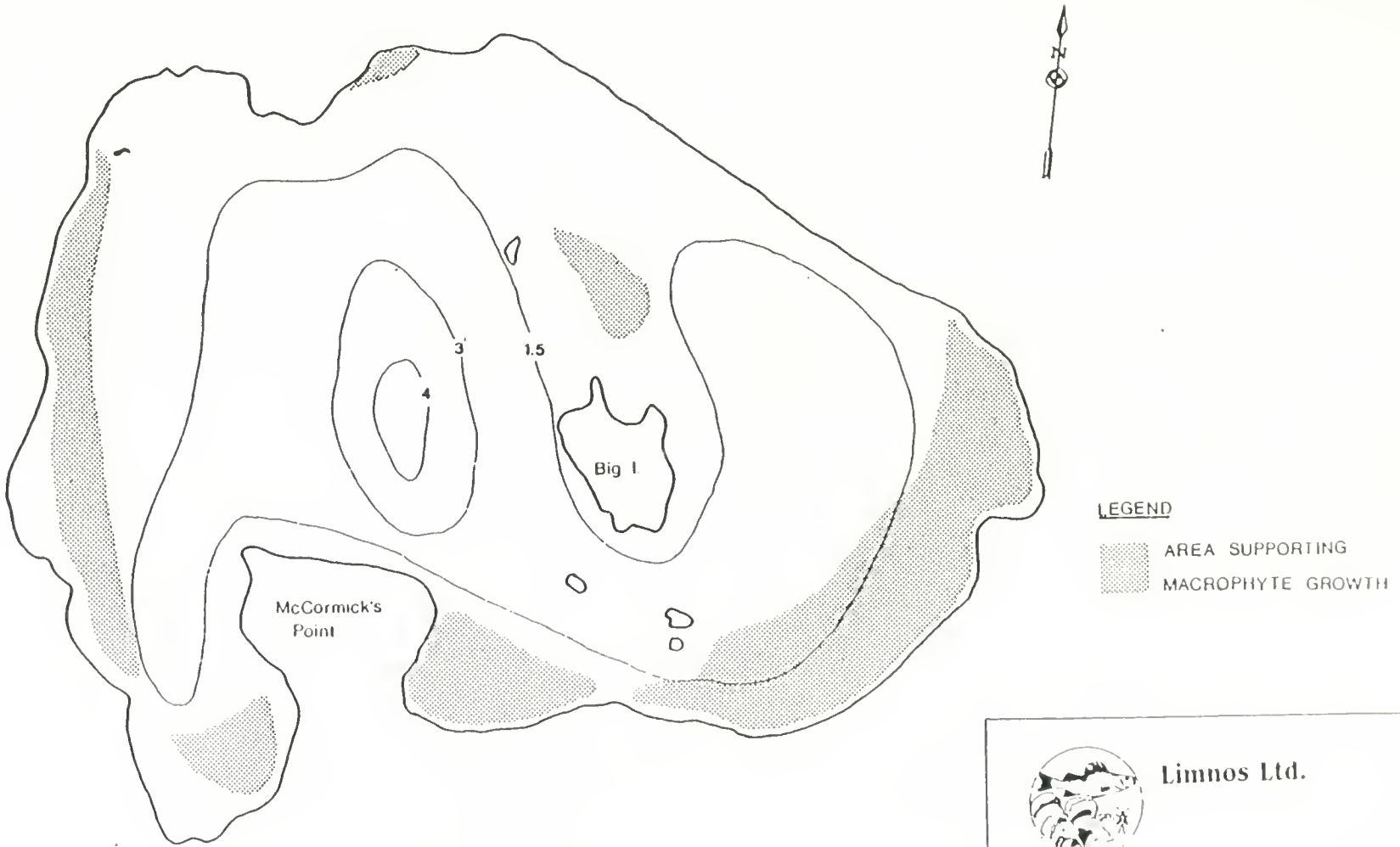


Figure 4. Distribution of Macrophyte Growth during Late Summer - 1987

Biomass and Nutrient Content

Early Summer Survey

Five locations were selected as biomass sampling stations. These stations are indicated on Figure 1. Table 3 in the appendix details species composition, wet (fresh) mass, and wet volume for each station. The average wet biomass for the five stations was 893.5 g/m^2.

The algae, Chara, was observed to form a major component of the macrophyte biomass during both aquatic plant surveys. Relative to vascular aquatic plants, there is little seasonal change in the development and decline of Chara. As well, Chara does not play a significant role in mobilizing nutrients contained in the sediments. For these reasons, the biomass data is also presented in Table 4 in the appendix with and without the inclusion of Chara. The average, wet biomass for the five sampling stations, without including Chara, was estimated to be 280.2 g/m^2.

Tissue nutrient information for collected macrophyte samples is given in Table 5 in the appendix. Phosphorus content ranges between 0.95 and 1.4 mg/g, and N content ranges 12.03 and 13.6 mg/g for vascular plant species. P and N content is significantly lower for Chara (0.51 and 10.56 mg/g, respectively), though low organic content (33.7%, Table 5) contributes to lower nutrient contents for this species. Nutrient content data is summarized below in Table 6 for both early and late summer survey periods.

Table 6 - Summary of Tissue Nutrient Content Data

Early Summer Survey

Species	Organic Content (%)	P (mg/g)	N (mg/g)
P. crispus	78.5	1.4	15.58
P. amplifolius	59.5	0.95	12.03
M. spicatum	72.9	1.22	13.6
Chara	33.8	0.51	10.56

Late Summer Survey

Species	Organic Content (%)	P (mg/g)	N (mg/g)
M. spicatum	73.45	1.94	17.3
Chara	31.59	0.65	7.23

Late Summer Survey

Table 7 in the appendix gives biomass and species composition information for plant samples collected at each biomass sampling location during the late summer survey period. The same biomass sampling stations were used during the late summer survey as were used during the early summer survey. The average biomass for the five stations was 412 g/m^2. Estimates of biomass excluding the effect of Chara (110.4 g/m^2) is given in Table 4 in the appendix.

Table 5 gives nutrient analysis information for M. spicatum and Chara samples collected during the late summer survey, and is summarized in Table 6 above. P and N content for M. spicatum samples were 1.94 and 17.3 mg/g, respectively. Content of P and N for Chara samples was 0.51 and 10.56 mg/g, respectively.

CONCLUSIONS

The major findings of the Puslinch Lake aquatic plant survey are summarized as follows.

1) A development of total biomass (wet and dry) and total contained nutrients is given in Appendix A (Development and Estimate of Total Biomass and Total Contained Nutrient Resources). The total wet biomass (excluding *Chara*) is estimated to be 151 t and 34.2 t, for the early summer and late summer survey periods, respectively. Contained P resources within the vascular macrophyte community (excluding *Chara*) were estimated to be 21.6 kg and 8.0 kg for the spring and fall survey periods, respectively, representing a summer P loss of approximately 13.6 kg of P. Likewise, contained N was estimated to be approximately 249 kg and 71 kg for the early and late summer survey periods, respectively, indicating a loss of 178 kg of N over the summer period.

2) There is little doubt that light availability presently limits biomass development and expansion of the growth area into deeper waters. Secchi depths measured at various lake locations were between 0.3 and 0.4 m during both survey periods. As large areas of the lake were found to have sediments suitable for macrophyte growth, increased light availability would be expected to expand the lake area occupied by macrophytes.

3) It could not be determined from the 1987 survey whether dense or widespread growth of *P. crispus* develops in the early spring, since the early summer survey occurred during the dieback phase of *P. crispus*.

The degree to which nutrients are possibly recycled or mobilized in Puslinch Lake by P. crispus is therefore unknown at this time. It is recommended that a spring survey of Potamogeton crispus growth be completed in a following year to document the status of this plant in Puslinch Lake and determine the importance of this species in nutrient recycling.

4) The average biomass of macrophyte growth (excluding Chara) declined from an estimate of 280.2 g/m^2 to 110.4 g/m^2 (wet mass) during the period between the two surveys. During the spring survey, macrophyte growth was dense enough to impede boat traffic in localized areas. However, biomass measurements of the magnitude observed in Puslinch Lake (100 - 300 g/m^2 wet mass) are small in comparison with biomass measurements that commonly range from 800 to 1500 g/m^2 (wet mass) in other enriched Southern Ontario lakes that support macrophytes.

5) Figures 1, 2 and 3 were developed from a hydrographic sheet originally produced by the Department of Lands and Forests. The date of the original hydrographic survey was not specified. The depth information provided on the figures serves mainly to indicate general depth regimes and major basin areas. Depth information obtained during the course of the macrophyte surveys indicated that depths are approximately 0.5 m less than shown on the chart.

REFERENCES

Limnos Limited, 1987. Rice Lake Study - Interim Report. Ontario Ministry of the Environment

Limnos Limited, 1988. Unpublished data - Cook's Bay (Lake Simcoe) Macrophyte Survey

Whitehead, B. 1980. Puslinch Lake Area Study. Wellington County Planning and Development Department.

APPENDIX

Appendix A - Development of Estimates of Total Biomass and Total Contained Nutrient Resources.

Tissue nutrient content is measured and expressed as a mass fraction of dried plant material. In order to relate field measurements of biomass (wet mass or wet volume measurements) to tissue nutrient content data, the relationship between wet mass and dry mass, or wet volume and dry mass of biomass samples is required. As the algae, Chara, displays little seasonal change in biomass, and does not significantly mobilize sediment nutrients, the effect of Chara has been excluded from the following estimates of contained, tissue nutrient resources. Exclusion of Chara from nutrient calculations, however, precludes using the relationships established by measuring the dry mass of collected biomass samples at Puslinch Lake.

Three biomass samples consisting of 100% Myriophyllum spicatum measured during the late summer survey had a wet mass to dry mass ratio of 0.13. Normally, the dry mass to wet mass ratio for vascular aquatic plants ranges between 0.07 and 0.15, depending on species and ash content. M. spicatum usually has a dry mass to wet mass ratio that is higher than other macrophytes such as the Potamogetons. Based on results of measurements of vascular plants from Lake Simcoe (Limnos Limited, unpublished data) and from Rice Lake (Limnos Limited., Rice Lake Study Interim Report, 1987) using collection and preparation techniques similar to those employed in the Puslinch Lake survey, a dry mass to wet mass ratio of 0.12 is assumed for the following developments of contained phosphorus and nitrogen.

Early Summer Survey

Total Areal Macrophyte Coverage - 54 hectares
Average biomass - 280 g/m^2 (Table 5)
Dry Mass/Wet mass ratio - 0.12
Average P content* - 1.19 mg/g (Table 6)
Average P content* - 13.74 mg/g (Table 6)

* average nutrient content of P. crispus, P. amplifolius and Myriophyllum spicatum samples collected during the early summer survey.

Total Wet Biomass = Areal coverage (ha) x 10,000 x average biomass (g/m^2)
= 54 X 10,000 X 280
= $1.51X10^8$ g
= $1.51X10^5$ kg
= 151 t

Total Dry Biomass = Total Wet Biomass (kg) x Dry mass/Wet mass ratio
= $1.51x10^5$ x 0.12
= $1.81x10^4$ kg
= 18.1 t

Total P resources = Total Dry Biomass (kg) x Average P Content (g/kg)
= $1.81x10^4$ x 1.19
= $2.16x10^4$ g
= 21.6 kg

Total N resources = Total Dry Biomass (kg) x Average N Content (g/kg)
= $1.81x10^4$ x 13.74
= $24.94x10^4$ g
= 249.4 kg

Late Summer Survey

Total Areal Macrophyte Coverage - 31 hectares
Average biomass - 110.4 g/m^2 (Table 5)
Dry Mass/Wet mass ratio - 0.12
Average P content* - 1.94 mg/g (Table 6)
Average P content* - 17.3 mg/g (Table 6)

* based on late summer survey, Myriophyllum spicatum data only

Total Wet Biomass = Areal coverage (ha) x 10,000 x average biomass (g/m^2)
= 31 X 10,000 X 110.4
= $3.42X10^7$ g
= $3.42X10^4$ kg
= 34.2 t

Total Dry Biomass = Total Wet Biomass (kg) x Dry mass/Wet mass ratio
= $3.42x10^4$ x 0.12
= $4.1x10^3$ kg
= 4.1 t

Total P resources = Total Dry Biomass (kg) x Average P Content (g/kg)
= 4.1×10^3 x 1.94
= 8.0×10^3 g
= 8 kg

Total N resources = Total Dry Biomass (kg) x Average N Content (g/kg)
= 4.1×10^3 x 17.3
= 71×10^3 g
= 71 kg

Seasonal Loss of P = 21.6 kg - 8.0 kg = 13.6 kg

Seasonal Loss of N = 249.4 kg - 71 kg = 178.4 kg

Table 1. - Fathometer Transects - June 22-24, 1987

Transect	Maximum Depth (m)*	Macrophyte Status
1	1.1	Thin, continuous growth of P. amplifolius, P. crispus, milfoil, Chara
2	2	Some P. amplifolius, P. crispus at 1m
3	2	Some P. amplifolius, P. crispus to 1m
4	3	Dead crispus toward north end of transect, Chara, Elodea near north shore
5	3	Chara, P. amplifolius near west shore, P. crispus remnants to 1.5m
6	3.3	Chara, P. amplifolius, P. crispus and milfoil to 1m near north shore
7	1.2	No plants - sand and gravel bottom
8	2	No plant growth
9	2	Thick growth of P. amplifolius, P. crispus, milfoil and Chara at 1m
10	2.25	P. crispus to 1.25m near NE shore
11	2.25	Thick P. amplifolius, Chara near east shore
12	1.5	No plants - rock, gravel bottom
13	1.6	P. amplifolius, P. crispus, milfoil at 1m, Chara near east shore
14	1.3	Milfoil, Chara near south shore
15	2.3	No plant growth
16	1.9	P. amplifolius, Chara to 1.1m
17	4.6	No plant growth

* Maximum depth recorded during fathometer survey

Table 2. - Fathometer Transects - September 1-4, 1987

Transect	Maximum Depth (m)*	Macrophyte Status
1	1.1	Some growth of P. amplifolius and milfoil
2	2	Minimal growth of milfoil
3	2.5	P. amplifolius, milfoil, Chara to 1m, dense near west shore
4	3.3	Chara, Elodea near north shore
5	2.4	Chara, P. amplifolius near west shore to 1m
6	3.2	Some Chara, P. amplifolius near north shore
7	1.3	No plants - sand and gravel bottom
8	2	No plant growth
9	2	Some growth of milfoil to 1m
10	2.1	Some Chara near north east shore
11	2	Some milfoil, Chara near east shore
12	1.9	No plants - rock, gravel bottom
13	1.6	Milfoil to 1m, Chara near east shore
14	1.4	Milfoil, Chara, Elodea near south shore to 0.8
15	2	No plant growth
16	1.7	P. amplifolius, milfoil, Chara to 1.1m
17	3.4	No plant growth
18	1.5	Some milfoil near west shore
19	1.6	No plant growth, ended transect at 1.1m
20	1.8	No plant growth

* Maximum depth recorded during fathometer survey

Table 3. - Biomass Sampling Results - June 22-24, 1987

Station	General Location	Wet Volume (ml/m^2)	Wet Mass (g/m^2)	Species Composition
B1	North of Big Island	687	625	50% P. amplifolius 25% Myriophyllum 25% P. crispus
B2	North of Big Island	not recorded	2,321.47	90% Chara 10% Myriophyllum P. crispus
B3	SE Corner of Lake	367.6	373.3	45% Chara 25% P. amplifolius 25% P. crispus 5% Myriophyllum
B4	East of McCormick's Pt.	1,366.70	1,259.60	95% Chara 5% P. amplifolius Myriophyllum Elodea
B5	Northeast Shoreline	1,329.30	1,377.30	80% Chara 10% P. amplifolius 5% P. crispus 5% Myriophyllum

All samples collected from water depths of approximately 1m.

Average Volume = 700 ml/m^2 (n=4)

Average Wet Mass = 893.5 g/m^2 (n=5)

1191.3

Table 4. - Biomass Results with Effect of Chara Removed

Early Summer Survey

	Biomass With Chara			Biomass without Chara	
Station	Wet Volume	Wet Mass	% Chara	Wet Volume	Wet Mass
B1	687	625	0	687	625
B2	not recorded	2,321.47	90	-	232.15
B3	367.6	373.3	45	202.18	205.31
B4	1,366.70	1,259.60	95	68.33	62.98
B5	1,329.30	1,377.30	80	265.86	275.46

Average Wet Volume (Chara removed) = 305.84 ml/m^2

Average Wet Mass (Chara removed) = 280.18g/m^2

Late Summer Survey

	Biomass With Chara			Biomass without Chara	
Station	Wet Volume	Wet Mass	% Chara	Wet Volume	Wet Mass
B1	46.7	40.0	0	46.7	40.0
B2	2,026.70	1,792	80	405.34	358.4
B3	40.0	14.6	0	40.0	14.6
B4	66.7	82.7	90	6.67	8.27
B5	160	130.7	0	160	130.7

Average Wet Volume (Chara removed) = 131.74 ml/m^2

Average Wet Mass (Chara removed) = 110.4 g/m^2

Table 5. - Macrophyte Tissue Nutrient Content Data

Early Summer Survey

Sample	Species	Sample Site	Organic Content %	P (mg/g)	N (mg/g)
T2CR	P. crispus	Transect 2	84.46	1.53	17.2
T3CR	"	Transect 3	86.93	1.55	19.3
T9CR	"	B2	81.16	1.39	14.6
T9BCR	"	B1	73.32	1.16	14.0
T10CR	"	Transect 10	66.7	1.40	12.8
		Average	78.5	1.40	15.6
T2A	P. amplifolius	Transect 2	56.5	0.77	11.2
T3A	"	Transect 3	62.63	1.04	11.4
T5A	"	Transect 5	59.39	1.05	13.5
		Average	59.5	0.95	12.03
T9MA	M. spicatum	B2	74.11	1.25	13.5
T9MB	"	B2	57.64	1.22	12.4
T9MC	"	B2	79.00	1.09	12.3
T3M	"	Transect 3	80.85	1.31	16.3
		Average	72.90	1.22	13.6
T15A	Chara	Transect 16	33.12	0.54	10.2
T15B	"	Transect 16	38.79	0.59	13.2
TD5	"	Transect 5	29.42	0.40	8.3
		Average	33.78	0.51	10.56

Late Summer Survey

Sample	Species	Sample Site	Organic Content %	P (mg/g)	N (mg/g)
TM19FALL	M. spicatum	B2	73.55	2.21	17.2
TM29FALL	"	B2	76.14	2.27	18.5
TM35FALL	"	Transect 5	70.67	1.35	16.3
		Average	73.45	1.94	17.3
TC19FALL	Chara	B2	28.91	0.66	5.9
TC29FALL	"	B2	30.2	0.78	6.0
TC35FALL	"	Transect 5	35.67	0.50	9.8
		Average	31.6	0.65	7.23

Table 7. - Biomass Sampling Results - September 2-4, 1987

Station	General Location	Wet Volume (ml/m^2)	Wet Mass (g/m^2)	Dry Mass (g/m^2)	Species Composition
B1	North of Big Island	46.7	40	6	100% Myriophyllum
B2	North of Big Island	2,026.70	1,792	458.30	80% Chara 10% Myriophyllum 10% P. amplifolius
B3	SE Corner of Lake	40	14.6	1.47	100% Myriophyllum
B4	East of McCormick's Pt.	66.7	82.7	18.7	90% Chara 10% Myriophyllum
B5	Northeast Shoreline	160	130.7	18.8	100% Myriophyllum

All samples collected from water depths of approximately 1m.

Average Volume = 468 ml/m^2 (n=5)

Average Wet Mass = 412 g/m^2 (n=5)

Appendix III. Results of selected questions in the August 1987 PLPOA survey of residents and visitors.

A. Visitors survey (48 responses)†

8. Please check the activities most important to your stay:

family	- 38
relaxing	- 38
swimming	- 34
boating	- 34
bar-b-ques	- 28
fishing	- 22
water skiing	- 20
overnight	- 17
casual play	- 16
nature	- 16
meeting people	- 15
visiting the area	- 15
picnicking	- 9
campfires	- 6

9. Check items which you would not consider doing during your stay:

swimming	- 29
fishing	- 18
boating	- 7

note: comments section for this question indicates that many respondents actually wanted to do the above activities but the poor condition of the lake prevented them from doing so (too many weeds, murky water, muddy bottom).

B. Residents survey (129 responses)†

5. Which of the following activities are important to you? You may check more than one.

swimming	- 99
boating	- 88
passive enjoyment of lake	- 86
fishing	- 79
relaxing	- 75
nature	- 63
visiting	- 51
casual play	- 43
water skiing	- 31
wind surfing	- 19
picnicking	- 19

7. Please check the items that you find unsatisfactory.

lake water quality	- 125
lake weeds	- 122
fishing	- 68
swimming	- 66
noise levels	- 33
restrictions on power boats *	- 20
boating	- 18
behavior of others	- 18
too crowded	- 11
public sections	- 4
water skiing	- 4

9. Type of improvement may answer all items

weed control	- 121
increase depth i.e. remove "mud silt"	- 117
water clarity	- 116
improved fishing	- 95
swimming	- 95

10. Are you agreeable to sharing the lake with others as you have in the past in order to receive assistance in cleaning up the lake, if available possibly from (Ministry of Environment, Ministry of Natural Resources) Township of Puslinch which could result in greater public access and use of the lake.

yes	- 107
no	- 14

note: comments section for this question shows that many residents wanted some restrictions on greater public access (i.e. less power boating, control number of people, entry fee for public)

12. Do you perceive the gulls to be a source of pollution on the lake?

yes	- 106
no	- 16

If you answered "yes", would you like to see controls on gull numbers instituted?

yes	- 101
no	- 0

17. Since, as a resident, you would be the most likely to benefit from improvements made to the lake, would you be willing to pay a fee?

no fee	- 28
less than $50 annually	- 16
$50-$100 annually	- 52
more than $100 annually	- 22

note: comments section for this question shows that both "no pay" and "should pay" groups had strong opinions defending their point of view

† Preliminary questions relating to number in party, location on lake, etc. are not presented here. Redundant or peripheral questions are not presented either.

* From comments section responses to this question